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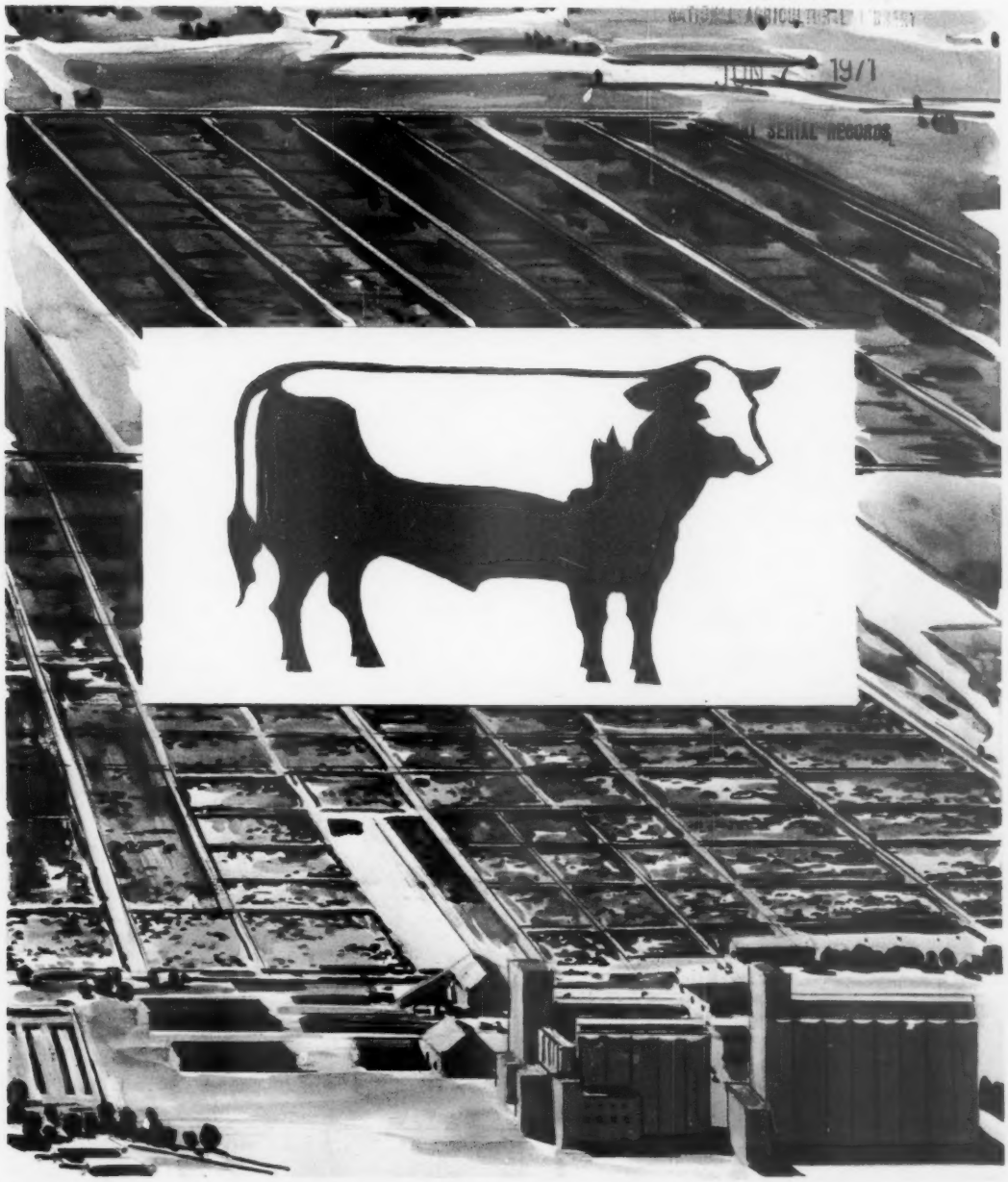
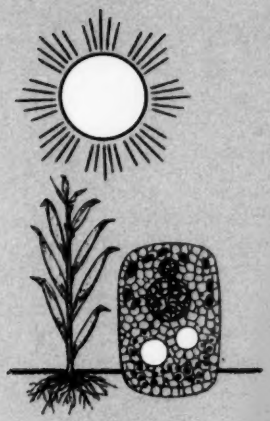


The Mounting Problem of Cattle Feedlot Pollution **Page 1**



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The High Cost of Protein

The cover design of this issue depicts one aspect of the change taking place in today's beef cattle-feeding industry. Capacity of the feedlot shown, which is located near Greeley, Colo., is 100,000 units. But we understand a newer one is being built nearby that will hold 200,000 animals.

In one way, we might say that the present emphasis on beef is one of the marks of our affluence. Here we are, feeding and fattening an animal that has a protein-conversion efficiency rating of about 8 percent. Which means that at a live-weight cost of 49 cents a pound, our protein is costing us $3.26 a pound. Even in poultry, with a protein conversion efficiency of about 30 percent, our utilizable protein is costing us $2.50 a pound.

This unfavorable ratio is probably one of the reasons chemists have put so much research effort on the production of single-cell protein derived from petroleum sources, for which the protein conversion efficiency approaches 100 percent. A multimillion dollar plant of this type is scheduled for completion early this year in France. And a midwestern U.S. company, which is planning to make edible protein from natural gas, reports that by 1975 they will be ready to market a synthetic protein product for human consumption—made possible by recent breakthroughs by polymer chemists in simulating nearly any natural product.

From our viewpoint, we don't care to even speculate on the implications of all this to the beef-cattle feeding industry. A more immediate job, perhaps, is to figure out what to do with all the waste material these super feedlots are creating. As the lead article suggests, author Frank Viets seems to have some workable ideas on that point.—W.W.K.

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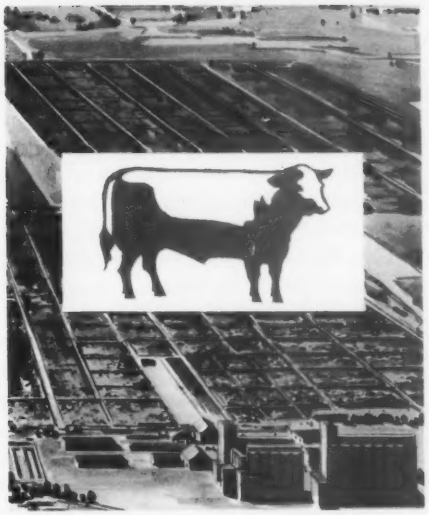
The Mounting Problem of

CATTLE FEEDLOT POLLUTION



FRANK G. VIETS, JR.

IMAGINE a situation where 1 million people are crowded together in an area no larger than 320 acres.

This supposition is not posed to draw attention to the possible consequences of the population explosion, but to raise concern for the pollution from a modern cattle-feeding operation in any one of several Midwestern or Western States. For in terms of biological oxygen demand (BOD) of waste, the number of cattle on many feedlots could be equated to a human population of the above magnitude.

Admittedly, equating cattle and humans on the basis of BOD of the wastes put through a sewage treatment plant is somewhat unrealistic. But the comparison does dramatize that never in history have we brought together such a mass of breathing, kicking, excreting life on land surface. No wonder we fear problems of pollution of air, surface and ground water, and even the soil itself. We have never had such an experience. I should point out that public health authorities are not yet concerned about such concentrations of animals posing an unusual threat to the health of workers and neighbors. However, a homesite near a feedlot may not be regarded as a pleasant or aesthetic environment.

In these days of suspecting pollutants everywhere and blaming the other fellow for them, agriculture has received its full share of accusations. Scarcely a day goes by that the newspapers do not carry a story about a fish kill, a law suit, a cease and desist order, or a zoning problem connected with animal feeding. Agriculture receives more black marks on the pollution scoreboard for wastes problems from animal production than from any of its other activities, even though soil sediment from farmland and suburban development is still land's greatest contributor to pollution (*13*).[1]

Trends in Size and Location

MANY cattle feeding operations are no longer a farm enterprise in which the farmer fattens the calves he grows or the carload or two that he buys to consume excess feed produced on the farm. It has become an industry with huge capital requirements: Purchase of most of the feed, hormones, cookers, veterinarians, computers for ration control, futures hedging, and manure handling equipment of a scale befitting the construction industry. The trend is to vertically integrate feeding, slaughtering, breaking, and purveying operations. A look at the balance sheets of the publicly-owned corporations shows

[1] Italic numbers in parentheses refer to Literature Cited, p. 8.

good to excellent return on investment. The economies of scale are not likely to be abandoned unless compelled by legislation or regulation in the name of pollution control.

Significant trends are also showing up in beef consumption and manner and site of production. Per capita beef consumption in the United States has increased about 3.5 percent a year for the last 20 years. About 16 million cattle are now fed annually. The number is increasing about half a million a year. In 1954, about 40 percent of our beef came from feedlots; in 1968, more than 67 percent. Density of animals in the feedlot has been steadily increasing to as high as 870 per acre, or 50 square feet per animal, in dry California and Arizona. Such high densities appear incredible, but they are used. Studies (*8*) in the Imperial Valley of California indicate that space less than 40 square feet per fattening heifer reduces gains and feed efficiency, and that 50 square feet of space was probably less desirable than 60. Corn Belt experiment station recommendations call for a minimum of 400 square feet per head on unsurfaced lots to 30 square feet per head in surfaced lots with open housing (*7*).

Because of the abundance and proximity of feed grain supplies, cattle feeding is concentrated in four areas. One is in southern California and Arizona, where about 3 million head are fed annually. This area, however, has showed little growth in the last 7 years. In fact, feedlot numbers declined 15 percent in California and 6 percent in Arizona for the year ending September 1, 1970. The number of lots with more than 16,000 capacity rose from 23 in 1962 to 36 in 1968.

The area that has grown most spectacularly is centered in the panhandles of Texas and Oklahoma where more than 5 million cattle are fed annually. The number of lots with more than 16,000 head was 33 in 1968, up from none in 1962. For Texas, the number on feed on September 1, 1970 was 7 percent higher than a year earlier.

The third area is in the central Corn Belt, where the number on feed rose from about 5.6 million in 1962 to about 8 million in 1969. In 1968, there were no operations with over 16,000 head.

The fourth area lies from eastern Colorado through Nebraska to the North Dakota line. Fed cattle numbers are now about 6 million, having doubled since 1962. There were 10 lots with more than 16,000 head in 1969. The number on feed September 1 increased 27 percent in Colorado and 14 percent in Nebraska over the number a year earlier.

Recognizing Pollutants

THERE are at least two approaches to the recognition of an environmental problem. One is the practical approach of the layman who notes a condition that annoys him and decides he can no longer tolerate it. However, environmental changes often occur slowly and may become significant before complaints arise. Then, too, there is the tendency to think of the past as Utopia and to forget the pollution that formerly was natural and accepted. With respect to cattle feedlots, the commonest nuisances are offensive odors, flies and dust in the air, polluted streams, an occasionally polluted well in or near a feedlot, and mountains of manure. (See photo, p. 3.)

The second approach is to learn something about the effects of a pollutant—whether it be a chemical, a particle, or heat—and determine by more scientific methods what it means to the environment. Many ecologists believe that we should know *all* of the consequences of a chemical in the environment before it is used.

In a feedlot, however, we are dealing with perhaps thousands of chemical compounds in feces that come from feeds, animal metabolism, and microbial byproducts produced either in the animal or by putrefaction on the feedlot surface. Little is known about these compounds or their environmental significance. Among them are large quantities of urea, which quickly hydrolyzes to ammonia, and volatile amines, skatole, indole, sulfur compounds, and organic acids that have bad odors.

The recent concern about the nitrosoamines and cancer in people (*2, 5*) illustrates the depth of our ignorance about specific toxins or their precursors in animal wastes. Carcinogenic nitrosoamines can form through chemical reactions of nitrite with secondary amines. Acidity favors the reaction. Nitrite in substantial amounts can accumulate in manures and feedlot soils either as a lag phase in nitrification resulting from low temperatures or high alkalinity, or as a step in microbial denitrification. Some evidence exists that secondary and tertiary amines (triethyl amine) occur in air where

hogs are confined; so we may have the reactants in feedlots, if we have the reaction conditions. Cattle feedyards, however, are usually highly alkaline because of ammonia and so we may be spared. Recent studies on aqueous systems of di- and tri-methyl amine and sodium nitrite in imitation of the reactions of nitrite used to preserve smoked chub salmon did not reveal the formation of detectable amounts of dimethylnitrosoamine, even at a temperature of 80° C., and pH as low as 5.8 (*6*). Public health authorities see no connection between cattle feedlots and the incidence of human cancer.

Gross Pollutants of a Feedyard

TABLE 1 gives some of the grosser measurements of significance in pollution. Values shown are on a daily basis per 1,000-pound animal, total for a 140-day feeding period per animal, and for an acre of feedyard stocked for a whole year with 360 animals. Composition data are from Taiganides and Hazen (*12*). The feeding period, average animal weight, and stocking rate are from a successful Colorado operation. These values can vary widely, but they still illustrate the enormity of the waste problem.

Why are the constituents in table 1 significant in pollution? If the organic matter gets into water, about 20 to 30 percent of the pollutant is readily decomposed by micro-organisms that use oxygen, the BOD of waste. The combination of the absence of oxygen in water and toxic concentrations of ammonia will kill fish. The dry mineral matter is largely soluble salts and gives an indication of the salt load. Because a corral is a salty place, the runoff can be high in salts. Very heavy applications of manure on land can accentuate a salt or salinity problem. In some areas, feeders add 1 percent salt to the ration to control urinary calculi—a practice that produces an enormous amount of salt, and much of it is sodium chloride. Sodium decreases the water intake rates of fine-textured soils receiving heavy applications of such manure. Nitrogen and phosphorus are significant because they may contribute to the eutrophication or overenrichment of water, which in turn leads to noxious algal blooms, that cause bad taste in water, damage it for water sports, and use up the oxygen when the algae die and decompose. Nitrogen can also be converted to nitrate by nitrifying organisms in either soil or water and be a specific pollutant of water supply.

Although the amount of waste per day per animal seems insignificant, a look at the total excreta for a whole acre of animals for a full year emphasizes the magnitude of the disposal problem. The 684 tons of dry organic and mineral matter for an acre of 360 animals for a year represents the "ashes" from about 2,800 tons of feed they consumed. These "ashes" are enormously enriched in mineral matter of all kinds, including microelements, potassium, phosphorus, and nitrogen. If we assume that 75 percent of the mineral matter is soluble in water and that it runs off or percolates in a foot of water, we have a salt concentration of 8,000 p.p.m. This water must be diluted from its electrical conductivity of 12 mmhos/cm. (a measure of salinity) with 47 acre-feet of pure water to get a conductivity of 0.25 mmhos, which is the upper limit of salt for a class 1 irrigation water. These calculations do not take into account the sodium hazard of the water, which

TABLE 1.—*Some constitutents of waste of a 1,000-pound bovine on a daily and feeding period basis, and on an annual acre basis with 360 head per acre*

	Per day	140 days	360 head/ac-yr
	Lbs.	*Lbs.*	*Tons*
Wet manure & urine	64	8, 960	4, 200
Dry mineral matter	2. 1	294	144
Dry organic matter	8. 2	1, 148	540
Water	53. 7	7, 518	30. 7 in.
Total nitrogen	0. 38	55	24. 9
Total phosphorus	0. 048	6. 7	3. 2
Total potassium	0. 26	36. 4	16. 8

would be low for animals fed a normal ration but high for those fed a high salt ration.

If all of the waste from an acre of animals were put through a secondary sewage treatment plant like that used for municipal sewage, the population equivalent would be 2,880 to 3,600 people. A 100,-000-head feedlot would be equal to a million people. Even though such treatment would remove sufficient BOD so that the water could be released into a stream, as much as 80 percent of the phosphorus and over 50 percent of the nitrogen would remain to pollute the stream. Furthermore, large amounts of water would be needed to run such a plant. Therefore, such a disposal system is never seriously proposed.

However, equally impractical systems of waste disposal are being proposed, such as complete lagooning of all waste, complete incineration, and allotment of land for the specific purpose of just decomposing waste. In my opinon, none of these schemes will turn out to be feasible or economic. *The solution to the problem is to return the solid waste to the land in sufficient amounts for near maximum production of crops without waste of the animal feces resource.*

Solid Waste Disposal

ACCORDING to the statistics of one large Colorado feeder, about an acre of irrigated land produces enough corn silage, alfalfa, and 100-bushel corn per acre to fatten 1.62 animals. According to table 1, 1.62 animals would produce about 2,340 pounds of dry waste. If an acre of cropland can safely use 11.7 tons of dry manure per year for the production of feed grains and corn silage, then only about one-tenth as much land is needed for productive waste disposal as for growing the feed. We need more information on the maximum amount of manure that can be used in crop production without pollution, waste of this resource, and converting land into a garbage dump.

People argue that since commercial fertilizers have become relatively cheap, a ton of average wet manure contains only about $1 worth of nutrients and therefore is not worth hauling and spreading. Since it does have to be scraped up and hauled somewhere, the argument that it isn't worth putting on the land does not appear to have validity. The old established feeding areas, such as the Corn Belt and northeastern Colorado, have little trouble in disposing of manure, but new areas such as southern California and the panhandle of Texas do. Cattlemen in the latter areas seem to prefer to make mountains of it. Historical, if not cultural, attitudes have something to do with the disposal of manure. Perhaps the old established areas have learned that there is some value to manure in maintaining soil productivity besides just the N, P, and K it contains.

Now that we have disposed of the manure, we can look at some of the water and air pollutional

aspects of the feedyard that are less easily handled than the solid waste.

The Nitrogen Balance of a Cattle Feedyard

ABOUT 25 tons of nitrogen an acre is excreted on a moderate density feedyard if it is used the year around (table 1). This nitrogen must be disposed of by hauling, runoff, deep percolation of nitrate and soluble organic nitrogen compounds, volatilization of ammonia and possibly other bases, or be denitrified to harmless nitrogen gas on the site. The magnitude of the pathways of loss depends on management, slope, nature of the feedlot surface and, of course, precipitation and climate. However, we have a very poor understanding of any one set of circumstances without making the situation worse by trying to understand all of the combinations.

About half of the nitrogen of feces is in urine as urea, which quickly hydrolyzes to ammonia. The feces contain no nitrate. The nitrate is produced on or near the feedlot surface by nitrifying bacteria whose activity depends on temperature, aeration, and the density of stocking. On a high density yard, nitrification is retarded by the high pH and toxicity of ammonia. For example, Stewart (*10*) added cattle urine to soil columns every 4 days for 8 weeks to simulate a dry feedyard with 150 square feet per animal. The soil pH rose to 9.9 from about 7, no nitrate was formed, and ammonia accumulated to about 670 p.p.m. All of the water in the urine evaporated and no leaching occurred. About 90 percent of the urinary nitrogen evaporated as ammonia. When urine addition was stopped and water additions substituted for 2 weeks, pH and ammonia decreased and nitrate accumulated.

Stewart's work illustrates some of the fluctuations in pH, ammonia accumulation and loss, nitrification, and nitrate movement that may occur under feedlot conditions to the urine, depending on management and location. Such management variables include the density of stocking, precipitation-evaporation relations (we call this part of climate), and continuous vs. intermittent feedlot use. We do not have sufficient measurements now to know what all of these variables mean in nitrogen pollution in the real feedlot world.

Gilbertson et al. (*3*) conducted an experiment at Mead in eastern Nebraska on unpaved feedlots with two cattle densities and three slopes of 3, 6, and 9 percent. For two consecutive feeding periods of 112 and 203 days, manure removed by hauling accounted for only 51 percent of the nitrogen excreted on the lots. For the 203-day feeding period only, with more complete data, nitrogen removal could be accounted for as follows: cleaning and hauling—59.1 percent, winter (snow) runoff—10.1 percent, spring and summer (rain) runoff—1.3 percent. Total removal accounted for only 70 percent of the nitrogen excreted. Some nitrogen entered the soil as nitrate, ammonia, and organic compounds, but the percentage is not known. It would be small. The rest was either denitrified or escaped as ammonia. The data on nitrogen removed in manure are biased because of dirt that is invariably removed with manure in cleaning unpaved feedlots. Although these figures are not conclusive, they are some of the best available on the nitrogen budget of cattle feces under unpaved feedlot conditions characteristic of most of the industry.

A complete accounting for all nitrogen entering a feedyard is now impossible, and perhaps the complete picture will never be known under actual operating conditions. Methods are not available now to measure the flux of ammonia and volatile bases from an open feedyard, but perhaps data could be obtained for cattle fed under total confinement. Under unpaved feedlot conditions, the rates of downward movement of nitrate and other nitrogen compounds are difficult to measure because of the apparent slow rates and the extreme heterogeneity of the unpaved feedyard, the conditions being different at the feed bunks, the watering troughs, and the resting places in the yard.

New equipment installed in the past year in feedyards by the Agricultural Research Service staff in Nebraska and Colorado, and by others elsewhere, will permit better measurements of all components of the feedyard water budget including water intake and spillage by the cattle. Better information should become available on the nitrogen budget and on runoff and deep percolation. Vacuum lysimeters (*1*) with a porous plate in the bottom so that suction can be applied automatically, equaling that on the soil water at equivalent depth, have been installed. Another innovation has been the installation of caissons—hollow steel cylinders 42 inches in diameter, extending from the lot surface to the water table, and large enough to permit personnel access.

Caissons facilitate measurement of redox potential, collection of gases and soil solution for analysis, measurements of water suction to determine flux, and the injection of isotopes, including nitrate tagged with N^{15}. These measurements are made and samples are taken through ports at various depths in the caisson wall.

Runoff

BEFORE the enactment of Federal and State laws and regulations prohibiting feedlot drainage directly into surface water, the custom was to build feedyards on slopes of creeks and rivers if they were available. Those days are gone. Many feedlots have had to either move or call on the services of engineers to design interception and disposal systems. Much of the data collection effort of recent years has gone into measuring the amount of runoff, its composition, and when the runoff would occur. Obviously, the problem is quite different for a feedlot located in the Salt River or Imperial Valleys than it is for one in eastern Nebraska or central Iowa. In eastern Nebraska, runoff ocurrs with rains exceeding 0.4 inch on 3- to 9-percent slopes. The runoff amounts to 0.531 times the precipitation minus 0.135 (*3*). The site conditions of roughness, wetness, and amount of manure cover at the time of rain are some of the factors affecting runoff-precipitation relations.

Runoff is potent with pollutants, as shown in the Nebraska data in Table 2. Winter and low-volume runoff is more concentrated than summer high-volume runoff as expected.

The disposal of runoff is outside the scope of this article, but some of the devices used include interception ditches, and aerated or nonaerated lagoons. In Nebraska, Agricultural Research Service engineers and microbiologists are modifying the feedlot surface with level terraces so that runoff is stored right on the feedlot until it can be pumped onto cropland, evaporate, or infiltrate right on the site.

Disposal of runoff is one of the costs in the humid regions that feeders in semiarid and desert areas find much less costly. If runoff cannot be disposed of economically in humid areas, cattle feeding will be forced westward to drier climates. A long-range balance between availability of feed grains and ease of runoff disposal will likely be established.

Air Pollution

AIR pollution from feedlots consists of odors, dust and ammonia. Odor control, except for occasional cleaning of lots, is an unsolved problem. People who get either direct or indirect economic benefits from cattle feeding seem to get used to feedlots better than other people. Most feedlot owners control dust

TABLE 2.—*Ranges of runoff concentrations from unpaved feedlots at Mead, Nebr.* (*3*)

Analysis	Range of concentration	
	Winter runoff	Rainstorm runoff [1]
pH	6.7–7.6	6.6–9.4
Conductivity (millimhos/cm)	3.0–11.5	1.0–3.4
Total solids (percent)	3.0–19.8	0.24–1.74
Volatile solids (percent)	1.4–10.7	0.12–0.73
Ash (percent)	1.5–9.2	0.12–1.05
COD (mg/l)	14,129–77,804	1300–8247
P (p.p.m.)	6.8–753.2	13.9–46.6
NH_3-N (p.p.m.)	670–2028	26–82
NO_3-N (p.p.m.)	0–80	0–17
Total N (p.p.m.)	1429–5765	65–555

[1] Concentrations for rainstorm-runoff are for the period April through June, 1969.

well by sprinkling their feedlots with permanently installed sprinkler systems. They prefer a wet feedlot to a dusty one that may cause pneumonia in their cattle. Dust control by high urinary output is given as one of the benefits of high animal densities used in arid regions.

Anyone who has gone into a closed chicken house knows about the odor of ammonia. Its odor in a feedlot is scarcely detectable. The amounts in air around feedlots are probably in the range of 20 to 100 parts per billion by weight. No health hazard is involved. However, studies in Colorado (*4*) show that lake surfaces in the vicinity of large feedyards can absorb large amounts of ammonia. One lake about a quarter of a mile from a large feedlot absorbed about 65 pounds of nitrogen per acre per year. Another lake about 1 mile from the feedlot absorbed only half this much, but it was enough to add about 0.6 p.p.m. of soluble N to the volume of the lake each year. This much N is regarded as sufficient for eutrophication if other factors are favorable. Obviously, control of runoff from feedlots is not going to prevent significant N input into adjacent lakes. However, in many Western States, lakes were built for the storage of irrigation water, and so irrigators and fishermen get a better quality of water. Swimmers, boaters, and city water supplies may suffer.

No aspect of pollution from feedlots needs more concentrated research attention than the chemistry of and olfactory response to the volatiles emanating from feedyards. Better management practices for control of odor can only be highly empirical until better understandings of all factors are obtained. Some people suggest that there are rings of odor around a feedlot, the quality of the smell depending on the distance. The current solutions to the problem are cleaning of yards, dust control, and zoning. The latter means that either the people or the feeder must move away. In established areas where housing has moved to the suburban-feedlot interface, it is usually the feeder that moves. Rise in land values has permitted him to do this, unless he had too much invested in feed-mixing facilities. Long-range zoning appears to be one, and perhaps the safest, answer. Perhaps the odor problem cannot be solved.

Deep Percolation

NOT much is known about the potential pollution of underground water by feedlots. Nitrate in groundwaters in Missouri has been attributed more to corrals than to fertilizer use on farms (*9*). In Colorado, some of the wells in or near feedlots have had to be abandoned because of unsuitability of the water, even for livestock use. Our core drilling studies in northeastern Colorado have shown that nitrate under cattle feedyards ranged from none to over 5,000 pounds of nitrogen per acre in 20 feet of profile; the average for 47 cores was 1,436 pounds (*11*). For other kinds of land use the average values were: virgin grassland—90 pounds, unfertilized wheat-fallow land—261 pounds, and irrigated land not in alfalfa—506 pounds. Under feedlots, nitrate concentration usually declines markedly with depth. The absence of nitrate in some profiles and the decline with depth in others indicate that denitrification is active under some feedlots. Samples of the water from the top of the water table under different kinds of land use showed no difference in nitrate content because of kind of land use. Samples averaged about 10 p.p.m. of nitrate nitrogen. Thus, we cannot say that feedlots are polluting the water table with nitrate. However, the water under feedlots had an offensive odor and was enriched in ammonium and soluble organic and phosphorus compounds. Therefore, we know that pollution is occurring, but we do not know how fast pollutants move to the water table nor how far they move in aquifers.

Current research of the staff of the Soil and Water Conservation Research Division of the Agricultural Research Service in Nebraska and Colorado in cooperation with the State agricultural experiment stations [2] indicates that unpaved feedlots pose no general threat to the quality of underground water. Although the contaminants that are moving may be concentrated, the rates of movement are very slow and feedlots occupy a miniscule part of the total area contributing ground water to aquifers. The surfaces of feedlots tend to seal with the tramping of animals and compaction of the surface. These generalizations, however, do not imply that wells in the immediate vicinity of feedyards cannot become polluted with noxious chemicals and odors.

Soil Pollution

SOILS used as feedyards apparently do not suffer

[2] This research is supported financially by the Water Quality Office, E.P.A.

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permanent damage to their ability to produce crops when they are returned to crop production. In the many instances of removal of feedlots to new locations to comply with pollution regulations or new ownership, there have been no complaints about poor crop yields. In spite of the jolt that the soil gets in heavy metals, salts, nitrogen and phosphorus compounds, the effects do not appear to be lasting. Annual weeds soon grow profusely in unstocked feedlots. Although zinc deficiency was a common occurance on old corral areas in California in the 1930's, the problem is not current.

Summary

OUR steadily increasing demands for well-finished beef and the apparent profitability of large integrated feeding and slaughtering operations indicate that feedlots will grow larger and not smaller. Cattle feeding is moving from a small farm enterprise toward an agricultural industry. We have never experienced such a concentration of wastes on so small an area. No wonder we are baffled by the problems of runoff, ground water and air quality deterioration. Most large operators are making a valiant effort to comply with water and air pollution regulations. However, the scale of their operations has expanded faster than the knowledge that could help them.

Because stream and lake pollution from runoff is now prohibited, engineers are challenged to design facilities that minimize runoff or dispose of it economically and, hopefully, beneficially. Runoff control is much more difficult in humid climates than in drier ones. Hence, the emphasis must be on economical systems or the feeding industry will be forced to move into drier climates.

Underground water pollution appears to be mostly a local phenomenon. Widespread contamination of aquifers does not appear probable.

Most of the unsolved problems lie in the air pollution area. The significance of increased levels of ammonia in the air to surrounding crops and lakes needs further study. Offensive odors and their control still await thorough application of microbiological and chemical research.

Manure can be disposed of and used as a resource if only a small portion of the land needed to produce the feed is available for manure disposal. Zoning appears to be one of the best solutions to the feedlot problem. Such zoning should include provision for adequate land for manure and runoff disposal.

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SOCIAL ASPECTS OF ENVIRONMENTAL POLLUTION

ROBERT M. ALEXANDER

In an effort to determine which environmental pollution problems are amenable to regional research, the Western Association of Agricultural Experiment Station Directors (WAES) has appointed a committee to study the topic, "Economic and Social Implications of Environmental Pollution." The idea for such a study developed from a discussion of a task force report on environmental quality prepared jointly by WAES and the U.S. Department of Agriculture.

As a part of its "homework" in making a full report to WAES, the committee reviewed and studied considerable data and resource reference sources relating to the overall problem. One of the papers so reviewed was written by one of the committee members, Robert M. Alexander, Director of the Air Resources Center and Water Resources Research Institute, Oregon State University, and former Assistant Director of the Oregon Agricultural Experiment Station.

Because of the interest Director Alexander's paper created among the Western stations and elsewhere, and because of its unique contribution to this oft-neglected area of environmental quality, the editors

of Review *felt it was worthy of being adapted for readers of our journal.*

Publication of this article marks the second instance within a year when the resource material of an experiment station study committee filled two roles so admirably.

TWO interrelated social issues are involved in environmental pollution problems. One issue centers around how far society can and should go toward a goal of pristine quality. How much do we want to pay, including loss of individual liberty, for prevention or abatement of pollution? Who will pay for it? The other issue concerns how decisions can be made about resource use (where waste disposal and residue problems are involved) so that *all* effects or costs are recognized and considered. This, in essence, is the side effect issue. It includes the sub-issue of how best to implement and enforce these decisions.

ESTABLISHING SOCIAL GOALS

UNTIL fairly recently, the social goals for environmental quality have been rather vague. The benefits of clean water, pure air, and uncontaminated land were recognized in a general way, but there were few yardsticks and no fully effective means of determining society's wants and desires. Attempts are now being made to sharpen existing measurement and assessment methods and develop new ones, in both the physical and social areas.

Pollution has too often been regarded as an "evil" that must be opposed and that can be solved by identifying the culprit responsible and making him stop. Pollution, in this context, has been considered something which others do that causes a nuisance, damages property, or menaces health, aesthetics, and recreational opportunities. An increasing awareness is developing that the solution is more difficult; that we all contribute to the problem; that much waste production is an integral part of life processes and human endeavor which has become more critical with increasing human numbers, concentration, affluence, and inventiveness.

Fixed emission sources, such as industrial plants, are generally the easiest to identify and abate or control. Emphasis on smoke abatement is an example. The increasing significance of sources difficult to identify, assign blame, and abate makes the concept of everyone contributing and sharing in the responsibility for and participation in group action more important.

This social issue, then, is how society determines and then reacts to basic goals on the use of resources where pollutants are involved. Such points as whether there is a "right to pollute" and whether waste disposal constitutes a "beneficial use" of a resource are being raised. The central question, however, is how much prevention and abatement society wants in view of the costs required and how to organize to accomplish this. Where should the division be between a *laissez-faire* approach at one extreme and an uncompromising goal of pure air, pristine water, and uncontaminated land at the other? How much are we willing to pay in higher product prices, taxes, and lost economic opportunities to achieve pollution control?

A related sub-issue is how the cost of preventing and abating pollution is to be borne. Should those who benefit from the use of protected resources pay? Or should society generally bear the cost? What share of the cost should be assigned to general welfare, handled through Federal subsidy to a local unit, or through providing a federal installation with no repayment required? Or should those who use the resource pay through some type of charge?

Another sub-issue is that of where the "burden of proof" should rest. Should, and if so, can it be placed on polluters or potential polluters? For example, can a polluter of air and water be required to show accurately what the composition of his wastes will be and to assess their effects on other values before he is authorized to make any discharge into the environment? This task is admittedly difficult, but such a principle is being followed in pesticide and radiation control. With pesticides, for example, the burden of proof essentially rests with the manufacturer to establish that his products will not leave harmful residues to affect human health or other values. The issue frequently revolves around whether or not licensing is an appropriate policy.

In any regulatory process, a vital sub-issue is that of infringement on individual liberty. Such infringement is a two-edged blade, however, in that the counterpart is an imposition on individual rights through forcing people to utilize a polluted

environment.

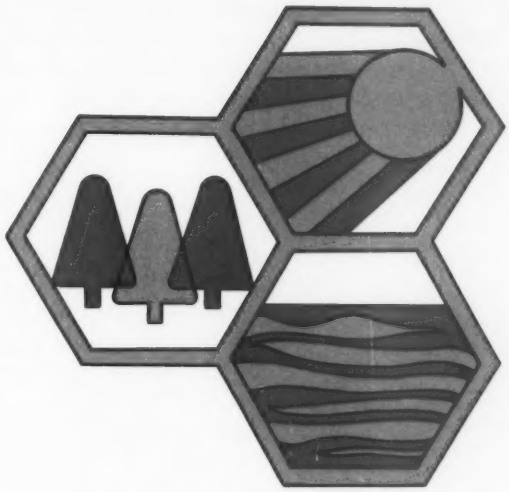
The concept of equating marginal social costs to marginal social benefits can serve as a sound guiding principle. In applying this concept, there are obviously many situations where social costs exceed social benefits. But the social machinery to bring about the desired balance between them does not exist. There are other instances where society may be going too far in the opposite direction. Imposing rigid limits on waste discharge where damage is negligible or low can also impose excessive burdens on society.

THE MARKET, SIDE EFFECTS, AND EXTERNAL COSTS

THE second major social issue of how to force the recognition of all effects centers around the market mechanism and its role in resource allocation. Through the market mechanism, prices provide automatic guidelines for production processes and for investment. But a condition for proper market functioning is that technical conditions of production and consumption be such that the costs fall upon the units responsible. If costs can be shifted to other units, the private costs will not correspond to the social costs, as expressed by the value of production that is given up, and resource allocation is distorted, even though the market may otherwise be functioning properly.[1]

Although nearly all production processes have side effects, many of them will not be important enough to cause concern. But not so with environmental pollution. Virtually the entire resulting damages and attendant costs are external to the unit actually releasing the wastes. Thus, important divergencies between private and social costs arise. Typically, social costs are not considered in the making of private decisions. The problem is how to bring this about.

When wastes are dumped into the environment without reckoning the external costs, resource allocation is distorted. Both production and consumption can be affected. For example, a pulp mill discharges wastes into the air without bearing any of the downwind costs, through damage to other



values or opportunities foreclosed, produces pulp or paper that is artificially inexpensive. It pays nothing for the use of a valuable resource—in this instance, the ambient air. This is the essence of the environmental pollution problem from an economic point of view. The social costs of reducing the usefulness or preventing the use of a resource in other valuable ways can be neglected. If a polluter does not consider the social cost of his actions, he may not limit the use of the resource to the extent of its capacity to assimilate or remove the waste. When he disposes of wastes at a cost to others, he makes less effort to treat waste products, to install control devices for minimizing discharges, or to modify production practices to reduce or eliminate the formation of wastes.

A society that neglects the external or off-site costs of waste disposal or undervalues them will waste too much and pollute too much. If such costs are not reflected in the decision of the discharger of wastes, there will be no incentive to reduce wastes through treatment, control devices, process changes, materials recovery, or other methods. When external costs are neglected, too few resources will be devoted to the treatment of wastes. More important, too much waste will be produced in view of the damage it causes. If no price or other restrictions are placed on the assimilative capacity of the environment, it will simply be overused. This is the general frame-

[1] In this paper, effects of this sort have been termed side effects. In economic terminology, they are classed as "external diseconomies" or abbreviated to "externalities."

work for considering some form of public policy intervention in waste disposal decisons. The only stipulation is that intervention should not impose a social cost greater than the one it is intended to prevent.

ALTERNATIVES FOR DEALING WITH POLLUTIONAL SIDE EFFECTS

SIX broad patterns are recognized for dealing with side effects from environmental pollution: (1) Informal patterns of persuasion; that is, stressing civic responsibility or making the release of environmental pollutants a social stigma; (2) establishing rights and enforcing them through private negotiation and adversary proceedings; (3) regulation, typically utilizing the police power of the State; (4) incentive payments for reducing pollution, or fees, charges, or taxes based on pollution discharges or damages from the discharge; (5) relating decision-making units that discharge wastes so that they are forced to recognize external costs; and (6) development of counter technology. Since the area of persuasion and civic responsibility is fairly obvious, it will not be treated further. Also, methods of dealing with side effects through developing counter technology are beyond the scope of this paper, so will not be covered. The other four possibilities, however, will be considered in some detail.

Establishment and Protection of Rights

RIGHTS and their protection have long been a cornerstone of social order. Rights can be protected against harm from environmental pollution through negotiations between the parties concerned, or through the more formal routes of adversary proceedings in the courts or enforcement action by a regulatory agency.

Private negotiations have historically been significant in pollution control and abatement and in forcing the recognition of side effects, and will, no doubt, always be utilized. For example, as aluminum reduction plants were constructed and hydrogen fluoride emissions and their effect on crops and livestock to adjoining farms became evident, private negotiations were often initiated. In some instances, cash settlements were made. In others, agreements were reached for the company to purchase the land and the owner to continue to operate it as a tenant. When private negotiations fail to produce a satisfactory method of resolving the side effect, the next logical step is to resort to a legal mechanism, either through a regulatory agency or the courts.

The court system was the earliest formal institutional pattern to deal with side effect problems from environmental pollution. Long before regulatory agencies existed, courts were functioning through a system of public and private rights to effect compromise and otherwise protect members of society from harmful side effects of pollution. This process was largely unaided by legislative action. In those cases where privately owned property was harmed, suit would typically be brought to protect the individual's private rights in a private-nuisance action. Where a number of persons were harmed, the suit could be a public nuisance action. For example, pesticide pollution that destroyed a public sport fishery resource would be in the nature of a public nuisance. Where either private- or public-nuisance actions are brought by private citizens, as contrasted to public officials, the courts have typically required the claimant to prove specific damages of a type different from those suffered by the public.

Effectiveness of Court Actions

THE courts have had, and should continue to have, a vital role in protecting rights against side effects—pollution. They must provide guidelines through handling certain benchmark cases; they must serve where a regulatory or incentive pattern is not operative; they must be available to back up a regulatory agency; and, finally, they must provide a recourse for those who feel they were dealt with unfairly by a regulatory agency.

There is little question, either, that courts alone are grossly inadequate to handle the many complex problems of resource quality maintenance. They have shortcomings that limit their effectiveness in certain areas. Among those generally cited are the following:

- Adversary proceedings are cumbersome and time-consuming.
- Courts can render fairly rigid requirements that may give little recognition to relative costs. Also, it is difficult for a court to make sure a decree is complied with.
- Difficulties can occur in public-nuisance actions

where damages are being imposed on a large group of private citizens, which may be improperly organized to prepare and present its case. It is also difficult, through either private or public action to bring suit for full damages. In addition, the injured parties must return to court each time they are damaged in order to receive any redress.

- Courts generally require claimants to prove damages, and many of the more subtle types of effects cannot be recognized and properly dealt with through court action. The regulatory process can function much more satisfactorily in this kind of situation. Also, burden-of-proof costs in court actions may be quite high.
- The effects of waste disposal into the environment are vastly complex, requiring scientific and technological expertise to determine the nature and extent of damages. The courts do not have this kind of expertise available except through outside experts.
- It is difficult through legal proceedings to deal with multiple-source pollutional problems or with the kind of secondary pollutants that are produced in the environment. Proof typically has to show causation—a difficult matter where no single activity causes the harm.
- Only those cases are considered by the courts that are brought to them. They do not, on their own initiative, exercise any continuing surveillance or supervision or in any way work toward prevention of wastes.
- Legal standards administered and applied by the courts in pollution cases tend to be general and vague. The words "reasonable" and "substantial" are typical.

The judicial system is now being pushed into a new role in fostering environmental quality, comparable to the role it played in civil rights. In the absence of what is considered adequate legislative and executive action, the courts are employed to modify or forge new social ground rules. Legal proceedings typically are initiated by an organization, such as the Sierra Club or the Environmental Defense Fund, against a public or private agency considered to be acting contrary to the public interest. By the suit, pressure is brought to bear on the political process. Action is accomplished through publicity and the public record of testimony, as well as through favorable court decisions.

A new focus is also being injected on the legal rights of a citizen to a clean environment, in which the burden of proof is being shifted from the public being subjected to pollution to the polluter. One primary base for implementation is the Ninth Amendment which provides that the enumeration of certain rights elsewhere in the Constitution does not deny to the people other rights not specifically set forth. Another base, the public trust doctrine, holds that government has the responsibility to protect the land—all once held in trust for the people—from abuse even though it is now in private ownership.

Project "Clean West"

As a result of its study, the WAES Committee on the Economic and Social Implications of Environmental Pollution recognizes three areas that deserve greater emphasis—land use studies, behavioral research, and research on institutions.

Because the land development pattern is intimately related to environmental quality, orderly planning is a vital ingredient in preventing future problems, not only on the land but also in horizontal and vertical space.

Because the term pollution implies a value judgment, science needs to know, among other things, how people form their judgments, how resource impairment or control affects public attitudes, and how public perceptions of resource quality compare to physical measures.

Because public institutions are deeply involved in understanding and managing environmental quality, research is needed to learn how to improve existing institutions and to create and evaluate new ones to deal with environmental problems.

These are the issues. As a means of getting started, the committee has proposed a 2-year planning and action program known as Project "Clean West." It is expected that a regional research program, based on the committee recommendations, will be initiated later this year.

Regulation

THE regulatory process for maintenance of environmental quality uses the same tools developed a century ago for public safety with the steam engine—inspection, standards, permits and licenses. Typically, in the initiation of a regulatory process, a need is established for control of a side effect. How this control is established will depend upon the nature of the side effect. Goals to maintain resource quality or to protect existing values are provided: Operational objectives may be set forth in the enabling legislation or left to the discretion of the regulatory body. Because of the complexity of problems in environmental quality, operational objectives have increasingly been left to the agency. At State and local levels, legislation often provides for a body of citizens to be appointed—a commission or board—to establish more specific policy guidelines and operational objectives.

The term "quality objective" has now come into standard usage in environmental quality and pollution control. It is the operational objective through which an agency specifies its basis for implementation of its abatement and control program.

The term "criteria" generally means the relationship of specific pollutants to their effect on various values and welfare. Unlike objectives, criteria do not imply any ideal condition. Rather they are formulated on the latest scientific information and modified as new information indicates any different effects from the pollutants of concern. The establishment of such criteria has come to be accepted as vital to the development of sound and enforceable standards.

Standards in the environmental quality area apply to the limits of a pollutant that can be released or that will be permitted to be present in specified segments of this environment. Most standards are now enforceable on a legal basis. Ideally, they will be based on the most recent criteria which, in turn, are based on the latest scientific knowledge of effect on various values or beneficial uses.

The distinction between quality standards and effluent or emission standards is particularly noteworthy. The former is concerned with permissible limits of the various parameters in the environment. The latter are levels that are permitted to be released: Without standards an agency must be prepared to prove that damage is attributable to a particular pollutant at a particular level before prosecution can be successfully carried out. Violation is easier to prove with scientifically defensible standards. They also provide guidelines to industries, municipalities, and others in the design and operation of treatment facilities and control devices.

The technique of licensing or the issuance of permits to authorize activities only within certain constraints has been used since the evolution of the regulatory process. It has found ready application in many aspects of environmental pollution control. Use of the permit system by a regulatory agency can force improved monitoring and reporting of pollution levels and more frequent inventories of

waste. Thus, new pollutional sources should go unnoticed less often than has been possible in the past. In addition, reports from industries and other units releasing waste will have much more official status and legal significance.

Although the regulatory process is by far the most widely employed means for pollution control and maintenance of environmental quality, concern is being expressed as to whether such heavy dependence on this method is in the public interest for the period ahead. Among the points being raised are: 1. It may cost more to achieve given levels of control than under the incentive method. 2. Regulation has been successful in dealing with gross and obvious forms of pollution, but it may not be a successful under more subtle (but possibly more socially costly) forms. 3. Enforcement tends to be spasmodic, with major efforts in early stages of the program. 4. Standards and other implementing techniques are not easily altered as new knowledge or technology is developed. 5. The pattern of establishing an authorized level of pollution release, based on some standard set to reflect a threshold level at which harm begins, has been labelled as socially, and in some cases technically, wrong.

Incentives

INCENTIVE methods are receiving increased attention to supplement, and in some instances replace, the regulatory-adversary process in controlling environmental pollution side effects. Incentive methods take one of two broad forms: payment for pollution prevented or abated, and a charge imposed for volumes and concentrations of pollutants released, or for otherwise causing environmental deterioration.

Because incentive devices are, in essence, market mechanisms to allocate or ration the waste-assimilative capacity of environmental resources, they have the great advantage of decentralizing the decision-making process—an advantage rather universally recognized with a market mechanism. Decisions on how much control or abatement to achieve at individual release points are shifted from a public agency to the individual dischargers. Decisions on how to achieve a given level of waste abatement or environmental quality would, likewise, be made by the individual decision-making units. In theory, both payment and charge patterns are aimed at providing an incentive to motivate polluters or potential polluters to restrict waste discharge to some more socially desirable or optimal degree than would exist without constraint. The differences between the two approaches center on how the incentive is applied and on matters of equity, acceptability, and administrative feasibility and cost.

Payment incentive schemes are aimed at motivating polluters to restrict pollution through some type of monetary award or concession. Examples are: tax concessions, federal grants to sub-government units, and direct payment from public treasuries for each unit of waste prevented in production or withheld from the environment.

A charge incentive system is the opposite of a payment plan in its application, but its counterpart in effect. But it has a number of advantages—principally in economic efficiency. The objective of an emission charge, like a payment incentive, is to achieve a desired level of pollution abatement in environmental resources. Theoretically, the schedule of charges should be based on external costs, including opportunities foregone, associated with increments of waste discharges into the environment. Charges could vary during seasons and locations to reflect varying levels of damage.

Charge or fee measures represent the closest approach to adopting a pricing system to the waste disposal field of any of the alternative implementation devices considered. On this basis, charge patterns would make the fullest use of the advantages of this decentralized decisionmaking process.

Relating Decisionmaking Units

ANOTHER method of bringing about a recognition of the external costs of pollutional side effects is to relate decisionmaking units that discharge wastes so that they are forced to consider the consequences and act accordingly. This principle is usually set up on some logical geographic or political boundary basis. For example, suppose two plants belonging to the same company operate in the same air shed or same watershed, so that the waste discharge of one unfavorably affects the other. In other words, the external costs of the upwind or upstream firm become internal considerations for the overall organization because it has downwind or downstream locations too.

Relating decisionmaking units constitutes both

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an implementation device for causing recognition of side effects and an organizational scheme to provide better resource quality management including more effective use of planning, zoning, incentives, and regulation. Thus, it is not homogeneous with the previously discussed methods, but instead can encompass one or more of them. The most drastic pattern of bringing about recognition of external costs through relating decisionmaking units is to socialize the resource. A less drastic pattern is that of regional or "problem shed" resource management. The British River Authorities and the German Cooperative Units, the Genossenschaften, are examples of this approach. Regional organizations with air sheds and river basins are being utilized increasingly in this country. Most have been restricted to service and coordinating roles rather than charged with resource management responsibilities. A limited number of airshed authorities and the Delaware River Basin Commission are the only such units in this country that appear to have resource quality management responsibilities approaching the German pattern. But both sanction and subsidy by Federal legislation exist to foster establishment of such patterns by State and local governments.

REASSESSMENT OF KEY SOCIAL ISSUES

HOW does society determine the trade-off between economic progress and side effects? Historically, the "will of the people" is supposed to be carried out by the government through laws, organizations, and other institutions. But even if we were armed with perfect knowledge to deal with the situation, the process seldom operates so precisely. Many other factors enter the picture. For one thing, the nature of the side effects of concern, from a physical and biological standpoint, is far from being clearly established. Also, the values for costs and benefits are not always available. Therefore, to resolve this broad issue, it might be profitable to consider the possible consequences of a number of propositions.

Our society wants a higher level of environmental quality at the sacrifice of other values.

The maintenance of environmental quality has become a major social issue. The American society is reflecting a willingness to make a greater sacrifice or pay a higher cost in opportunities foregone and in other ways to obtain this quality. Although earlier characterized as the emergence of a "clean environment" group, the movement is now broad-based. It has been developing along lines comparable to the conservation movements that resulted earlier in this century in new patterns in management and use with timber and soil resources. As was true in those areas, certain evangelical fervour is present. And, as in many issues of this nature, certain governmental agencies are playing strong advocate roles.

Knowledge is becoming the "new property." Economic and political power is shifting to those associated with the new property of knowledge. This altered structure of society is recognized as a vital factor in adjusting the trade-off between economic development and the maintenance of environmental quality.

The American culture that has placed a high value on future versus present consumption and on the maintenance of a "natural" environment is another factor in this altered trade-off. Still another factor is the increasing affluence of the society. There is now a greater opportunity to make sacrifices in material goods and services production where side effects are involved. Also, with greater economic security, people look for other "causes."

Newly developed social attitudes along with various physical parameters have produced a deepening concern for environmental quality. These physical and social parameters have in turn led to a questioning of traditional values and established institutions. They have led also to virtually unprecedented political activity, particularly at the federal level. The result has been new legislation, agencies, and coordinating mechanisms; regrouping of existing agencies; and altered patterns of federalism.

An equating of social benefits against social costs should be the guiding principle in establishing goals and objectives in maintaining environmental quality.

It must be recognized that this equating is a conceptual framework for decisionmaking rather than the calculation of precise benefit/cost ratios. Many costs and benefits are difficult, if not impossible, to meaningfully quantify. Concern is being expressed with attempts to apply benefit/cost techniques too precisely in decisionmaking where the market does

not function to provide values. Nevertheless, the concept is still highly valuable and appropriate as a guiding principle in control policy. Realistically, the setting of any quality criteria or standard relating to well-being of any kind involves making at least an implicit calculation of a benefit/cost ratio.

As Harold Thomas noted in his often cited *The Animal Farm: A Mathematical Model for the Discussion of Social Standards for Control of the Environment,* "the criteria of quality represents a balance of costs and benefits. . . . the setting of any quality criteria or standard relating to health and well-being inevitably entails making an implicit estimate of a cost/benefit ratio based on whatever data or other factors are available for judgment. In situations where the costs are known within reasonable limits, the establishment of a standard amounts to assigning a certain utility to human life, health or well-being . . . The setting of a standard is in effect an imputation of a certain finite level of utility or benefit accruing to life, to health, or to well-being."

Placing the burden of proof on the polluter or potential polluter can foster implementation of desired public control policy.

Should society bear the burden of proving that pollution is occurring and rendering harm? Or can this burden be shifted to the polluter or potential polluter to prove that he is not polluting or will not pollute?

The pattern on where the burden of proof rests has varied markedly with different environmental pollutants. Through the licensing procedure, which constitutes the major control pattern with both peaceful use of atomic energy and with pesticide manufacture, the burden of proof has been shifted to the polluter or potential polluter. In the case of air pollution, the pattern of licensing is receiving certain consideration and limited application. It would appear that there may be additional possibilities for applying this type of pattern in other areas.

A shortcoming of the licensing-type regulatory process is that it can easily become static, a characteristic of the regulatory process in general. To be effective, it needs to be altered to keep pace with availability of new technology and scientific understanding, and continually guided by the principle of balancing social benefit with social cost.

Economic efficiency must be an important, but not an exclusive, consideration in setting control patterns.

Because the abatement and control of environmental pollution is so costly, it is extemely important to attain the highest possible return for the resources and money expended. Unfortunately, this desirable state of affairs does not always hold true. For example, one of the main criticisms of the adversary-regulatory process in achieving side-effect control is its failure to stand up well under economic scrutiny. Proper kinds of incentive measures could meet this test far better.

Finally, the point needs to be stressed that economic efficiency is only one of several objectives which need to be considered in determining how best to accomplish a control objective. Obviously,

the cost of regulation or otherwise dealing with a side effect must be considered as a legitimate cost. But also the social considerations, centering on matters of equity and redistribution of income, must be evaluated.

New patterns of relation between the levels of government and new jurisdictional forms are areas justifying far greater attention.

Public action in air and water pollution started at a local level. More progressive states, or those with greater problems, entered the picture to provide certain intrastate uniformity and coordination, but still left much of the responsibility for program implementation at a local level. As the Federal government has become concerned with public action in air and water pollution in the past 15 years, the same principle has guided their action. The basic goal appears to be that of insuring a mimimum quality standard nationally, while depending on State and local units for most enforcement procedure.

As in so many areas in our Federal system of government, we are seeing a balancing of responsibility between levels of government. With programs starting at a local level, but in which major interdependencies exist, higher levels of governmental authority are required. With programs established at a Federal level—as the situation has permitted—participation at a State and local level has been sought.

One of the most vital issues in the environmental quality field at present is whether new special subunits of government are needed or if existing jurisdictions can function adequately in this area. As new subunits of government are authorized, a number of key questions arise:

1. What will be the relation of the newly created subunits to existing governmental jurisdictions?

2. How much authority will be vested in the new subunit? Will it be possible to empower them with authority to initiate a true resource quality management program? The trend in this country to date has been for subunits, such as those in the air pollution field, to have more limited authority.

3. How will representation be achieved? Will parties affected by decisions of such an organization have a voice in the decisionmaking process?

Although this area of the structure and operation of special authorities is one that needs much attention, certain general guidelines can be suggested. One is that an authority of this type needs to be vested with sufficient power and flexibility to initiate and conduct a program that can include all kinds of alternative instruments that are available. A second would be that a mechanism to permit formal representation of all interested parties needs to be adopted.

A CONCLUDING REFLECTION

THE critical issue today is the nature, speed, and extent to which the physical world is changed to suit man's purpose. Science is providing, at a rapidly accelerating rate, the knowledge base on which new technologies can be developed. And now science-based technologies have been emerging and are being adopted at a phenomenal rate. The conventional philosophy has tended to be "if it can be done, it should be done."

This consistent pattern of change, which is such a paramount feature of our society, has been particularly dominant in agriculture. Indeed, agriculture is one of the more dramatic examples of ordered technological change for bringing material advances. Principles developed through basic research were rapidly exploited through specific application to quantity, quality, and efficiency problems in agricultural production. The results are so well-known—at least to agriculturists—that they need not be documented here. The side effects, however, are just beginning to be recognized. No longer are they considered as secondary issues. Instead, side effects are now a primary criteria in the consideration of new technologies.

If society intends to capture the full potential of purposeful scientific and technological change—with all its material progress and major side effects—then it seems imperative that social change must keep pace. In other words, the social world will need to be modified to reflect the existing and potential changes in the physical world. New and modified social institutions will need to be structured to provide improved mechanisms for balancing the benefits from physical change against the costs to society of the inevitable side effects. No other alternative seems logical if society is going to adequately cope with this unique problem of modern man.

The AUSTRALIAN Milk Biscuit

R. A. BUCHANAN

THE nutritional value of milk as the staple food of infants and as an important part of the diet during the formative years is widely acknowledged. But unfortunately neither fresh nor reconstituted milk is available in some countries, and practical problems make it difficult or impossible to introduce either one. For many years, however, research efforts have been directed toward utilizing the nutritive qualities of milk in forms that would be less affected by the restrictions in the fresh product. The story of the Australian milk biscuit [1] is one example of the kind of success that science and technology have been striving for.

New Foods Philosophy

ALTHOUGH research on the development of new dairy products and new uses for dairy products has been carried on since 1950 in the Division of Dairy Research of CSIRO,[2] it was not until 1964 that a new and different approach to this work was proposed. The occasion was an International Milk Promotion Seminar in Canberra, and the approach was identified in this way:

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[1] Products known as "cookies" in America are called "biscuits" throughout most of the English-speaking countries of the world.

[2] Commonwealth Scientific and Industrial Research Organization, Australia.

"Butter and cheese go well on bread but what goes well with rice or maize or taro or cassava? It seems that modern technology should be able to devise dairy foods more suited to such diets than are the traditional western dairy products. Development of dairy foods specially suited to the needs of the enormous populations in these countries could greatly increase the total potential dairy market" (*3*).[3]

It was obvious enough then that in most underdeveloped countries the great need was for more protein. There are two reasons why milk protein is so useful in this role: (1) It is a very good quality protein, and (2) it is high in lysine and therefore improves the quality of cereal proteins with which it is mixed in the diet.

Milk protein was already available in several forms. Pasteurized, sterilized, evaporated, sweetened condensed milks and full cream milk powder are readily available and contain all the nutrients of milk. Cheeses contain varying amounts of fat, most of the protein, and very little or none of the sugar of milk. But all of these were more expensive sources of protein than nonfat milk solids (NFMS) or casein.

As a source of protein, casein is cheaper to produce than NFMS, but we thought the economics of casein production could be improved because casein represents only about 80 percent of the protein in milk. The other 20 percent is discarded.

That reasoning, and our subsequent research, eventually led to the development of a successful procedure for recovering about 96 percent of the proteins in skim milk as "co-precipitate" (*4*). Later work (*7, 8*) greatly improved this manufacturing technique and demonstrated a wide range of uses and properties of co-precipitates prepared in different ways.

Co-precipitate production has now reached several thousand tons annually. Twelve large and efficient producers are now licensed by the CSIRO and are well equipped to meet the growing demand for different types of co-precipitate.

Biscuit Development

IT was largely the development of co-precipitate that made the milk biscuit development possible.

In a casual discussion with a few dairy industry leaders, they asked if we could provide a form of milk more suitable for use in underdeveloped countries where fresh milk is not available and cannot be made available because of transport and storage difficuties—where even milk powder is not really suitable because clean water is not available. This applies in many primary schools where they have an added complication of insufficient time to prepare food for children.

Biscuits (cookies) seemed to have all the prerequisites except nutritive value. How could this nutritive value be improved?

Nonfat milk solids—Small amounts of nonfat milk solids (NFMS) can be added to biscuits, but when very large percentages are added to give a reasonably large protein content, the browning reaction interferes. This reaction between proteins and reducing sugars such as lactose leads to losses in protein quality and browning or even burning of the surface of baked goods. Since NFMS contains about 50 percent lactose, only small quantities can be used in conventional biscuits. Large quantities cause excessive browning.

Caseins—Casein is virtually pure milk protein containing no lactose. Spray-dried sodium caseinate can be dispersed readily in a biscuit dough but absorbs about four times its own weight of water. The result is a sticky, high-moisture dough which is very difficult to bake.

Co-precipitates—Co-precipitate, however, seemed to be an ideal protein supplement. Our research showed that high-calcium co-precipitate could be spray dried in a form which absorbed much less water than sodium caseinate, yet would disperse readily in a biscuit dough.

Thus, a biscuit was formulated with roughly the same fat/protein/carbohydrate ratio as in whole milk solids. Butter was used as a source of fat, co-precipitate as a source of protein, and cane sugar plus wheat flour as carbohydrate. With some leavening and flavoring added, a quite acceptable home-made style shortbread biscuit was the result.

Commercial Development

THE next move was to try to adapt the manufacturing process to a scale that would be commercially feasible. A local biscuit manufacturer agreed

[3] Italic numbers in parentheses refer to Literature Cited, p. 24.

to cooperate and eventually produced about 350 pounds of milk biscuits in raspberry, chocolate, and vanilla flavors with extra vitamins and minerals added (*9*).

Storage trials showed that the biscuits had very good keeping quality even at tropical temperatures. Nutritive value of the protein was superior to casein, and equivalent to fresh whole milk. The extra vitamins and minerals which had been added insured that in this respect the biscuits were superior to milk. Moreover, everyone apparently liked the biscuits—not only trained taste panels, but also adult consumers and children in Australia and overseas. Although an enormous market appeared to be ready for the product, there were no marketing organizations or facilities to do a market survey, to seek out the areas where the biscuits were both needed and wanted, and to promote sales. As a result, it was four years from the time the first pilot run was produced until the next small 4,000 lb. production run was made.

A Need Arising

PUBLICATION of the composition of the biscuits, their nutritive value, and keeping quality in the *Australian Journal of Dairy Technology* in 1967 aroused little interest and drew no response. But later that year, two doctors at Prince Henry Hospital in Sydney reported on a group of Asian students in Sydney suffering from lactose intolerance and drew attention to the fact that this problem is common among non-Caucasian people (*6*). Amidst the publicity that followed this announcement, lactose-free milk biscuits were reported to be a possible answer for the students—and for the dairy industry too, if the overall market for dairy products in Asian and African countries was to be extended.

At about the same time a delegation from the Zambian Dairy Produce Board was visiting Australia as guests of the Australian Dairy Produce Board and the Department of Trade and Industry. The Zambians had been invited to Australia, because they were becoming big buyers of dairy produce—mainly anhydrous milkfat and nonfat milk solids. These products were being recombined into pasteurized milk to meet the enormous increase in demand since the government of this newly independent State had started to subsidize milk consumption in their poorer, densely populated areas.

One of the chief concerns of the Zambian officials was that there were many rural areas where milk could not be delivered daily. This situation effectively blocked any move to introduce a school milk scheme, because 80 percent of children lived in rural milk-deficit areas. The Australian milk biscuit appeared to be the ideal answer for the problem, particularly since the Zambians could make their own biscuits and there were good prospects of using increasing amounts of local raw materials to eventually replace imports.

The Zambian Biscuit

AFTER a prototype milk biscuit—especially designed for Zambian conditions—had been produced, the Australian and Zambian Dairy Produce Boards sponsored a visit to Zambia, and the delegation took with them a small suitcase full of biscuits. Local nutritionists and a few field trials suggested there should be some small changes before full scale acceptability and nutrition trials were carried out.

When these changes were made, the result was a fairly hard, crisp, crunchy, 10 gram, doughnut-shaped biscuit with a touch of vanilla added but described by most people as "milk." It contained 20 percent protein, 20 percent fat and was supplemented with vitamin A, thiamin, riboflavin, niacin, calcium, iron and iodine (*5*).

With the help of a $2,000 grant from Community Aid Abroad and some smaller donations from other charitable organizations, about 2 tons of these biscuits were produced in October 1969, and shipped to several countries, including Zambia, for nutrition and acceptability trials. Soon afterwards a group of copper mining companies in Zambia agreed to donate about $16,000 worth of biscuits to the Zambian government for further trials arranged by the local Food and Nutrition Commission.

Shortly thereafter, the general manager of Arnott-Brockhoff-Guest Pty. Ltd., (the company which had been making the biscuits in Australia), visited Zambia to discuss detailed arrangements for commercial sales. In February 1970, 60 tons of milk biscuits were shipped to Zambia and for the rest of the year commercial quantities continued to be exported.

To simplify distribution, only the original one flavor (vanilla) has been used. The biscuit's image as a milk product has been fostered with the slogan

"EAT MORE MILK."

A pilot-scale plant capable of producing about a ton of milk biscuits per 8-hour shift has been donated to the Zambian government by the Australian government. With the help of some raw materials donated by the World Food program, this plant will be operated in Zambia by their Dairy Produce Board—a statutory government authority which operates as a commercial venture buying locally, importing, processing and selling most of Zambia's milk and dairy products.

A year ago it was thought that a plant producing a ton of biscuits per day would be sufficient to meet the initial demand. But it was obviously a wise move to test the market with imported biscuits before embarking on local production. Now it appears the demand may have outstripped the capacity of this plant before it starts.

Quite a few other countries are interested in installing plants similar to the one being tested commercially in Zambia. If it is a success there, the same general pattern will probably be followed elsewhere. Meanwhile, nutrition and acceptability trials are proceeding in many other countries. A few of those already completed were described by Buchanan (2).

Utilization and Acceptability

THE Australian milk biscuit was originally designed as a milk substitute for children in schools where liquid milk was not available. It still seems admirably suited for this purpose but like most wholesome foods, it is useful in a multitude of other situations.

As a general snack food for infants, children, the elderly, and diet-conscious adults, it has obvious nutritional advantages and a surprisingly wide-ranging general acceptance.

CARE-Indonesia distributed the biscuits at two schools in the Djakarta area. Both reported pleasure at the ease with which the snack could be handled, stored and distributed. Compared to CSM,[4] pilferage rates and losses from breakage and leakage were reduced. After four weeks, teachers reported that the children liked the biscuits very much; they purchased less sweets from peddlers operating outside the school grounds; absenteeism through sickness and other reasons decreased; the children "studied better" and were "learning well in the class room."

The Australian Red Cross arranged an acceptability trial with 2- to 4-year-old children at an orphanage in Saigon, South Vietnam. Three biscuits were as much as they could eat at a time. In common with most other Asian and Australian children, they prefer softer biscuits whereas the African children prefer them harder.

The Department of Public Health in Western Australia arranged that the biscuits be tried for acceptability over a cross section of Aboriginal children in Western Australia. Out of 514 children tak-

[4] CSM is a dry mix of corn, soybeans, and nonfat milk solids containing about 19 percent protein. It must be cooked before eating.

Does the U.S. Need a Milk Biscuit?

A few pilot research studies in the United States have shown that non-Caucasian children often cannot or will not drink milk. In an effort to learn the reason of this phenomenon, the U.S. Department of Agriculture has awarded a research grant to Johns Hopkins University, Baltimore, Md.

Because milk is an important staple of school lunch programs for children from disadvantaged areas who often need additional protein and calcium, the Department feels it is important to learn more about its effectiveness as a supplement when many of the children may have a family history of nonconsumption of milk or may reject it because it makes them feel sick. It may be that attempts to upgrade nutritional status with milk and milk products is largely self-defeating, both in the United States and abroad where large segments of the population are non-Caucasian.

The research, which will involve 450 elementary school children from two Baltimore city schools, one predominantly Negro and one predominantly white, will provide information on the number and racial profile of healthy school children who refuse to drink cow's milk and on the possible relation of this refusal to inability of the body to properly use the lactose or milk sugar that makes up almost 40 percent of the solids in fresh whole milk.

ing part, only 4 disliked the biscuits. The conclusion was that "the biscuits proved very acceptable to the Aboriginal children taking part in the trial and there seems to be no doubt that the Australian Milk Biscuit would be accepted by Aboriginal children as part of their regular food intake."

For 10 months, milk biscuits have been sold in the CSIRO Division of Dairy Research canteen at morning and afternoon tea times. Sales are consistently higher than for any other type of biscuit or cake.

A most interesting use which has not yet been fully investigated is in the feeding of people who are intolerant or allergic to liquid whole milk. Lactose intolerance has been reported to be fairly common among many races and can cause intestinal upsets if large quantities of milk or milk powder are consumed by people not accustomed to it in their regular diet or by invalids in whom gastroenteritis has destroyed the lactose-splitting enzyme in the intestine, lactase (*1*). Lactose-free milk biscuits seem an ideal, pleasant method of keeping up the supply of high-quality protein in the diet of such people.

Allergy to milk protein is apparently less common than lactose intolerance in most communities, but many of these cases may also be assisted by milk biscuits. The milk protein, co-precipitate, used in making the biscuits does not include 3 to 5 percent of the small protein fractions in whole milk. It is thought that these discarded fractions may cause most cases of milk protein allergy, and milk biscuits could therefore be non-allergenic for most people. There is scope for much more research to clarify this point.

Future Prospects

IT appears likely that within the next few years milk biscuits will become even more widely accepted in many different countries than they are now. In most cases it can be expected that consumers will be impressed by slogans such as "EAT MORE MILK," and the image of "the goodness of milk" will make biscuits more acceptable. Nutritionists can be expected to support the product, partly because of its high content of high quality protein. But if this product is to make the greatest possible contribution to the national diet and the economy in any country, it should be modified to suit the needs of that particular country.

A biscuit rich in milkfat, milk protein, cane sugar, and wheat flour is quite satisfactory in the United States or Australia. But in other countries that do not have Australia's abundance of wheat and dairy products, other raw materials should be substituted as much as possible without destroying the appeal and nutritive value of the original product. To design products that meet this criterion is the task facing food research scientists.

If a high-protein biscuit market can be established, it could and should serve as an outlet for local agricultural produce. It is an ideal medium in which to use surplus and novel protein foods. So by offering a new market, it may stimulate production and industrialization in developing countries.

A New Approach in Research

THE development of the milk biscuit involved an unusual approach not only for the dairy industry but also for food research. It involved admitting that milk is not the perfect food. It arose too from thinking of the needs of the consumer rather than the need to find a new outlet for the seller's products. It relied very heavily on a technology (of biscuit making) not available within the dairy industry or the research institute at which the work was initiated.

When this technology was needed, a reasonable approach by a highly regarded organization (CSIRO) to an alert company produced 100 percent co-operation. Before the commercial possibilities were proved, the research workers took on the job of development. Then after the commercial possibilities were proved, the researchers still retained an active interest, pushing the snowball and playing a vital role in maximizing the product's potential and rate of development.

The publication of research results was used to stimulate the project, but this alone was not enough. Other forms of publicity, including the trade press and general press publicity, both in Australia and internationally, were needed to stimulate maximum interest in the project.

Finally, many individuals in many different organizations took a personal interest in the project and took pride in making a special contribution. No person or organization has dictated how others must behave when handling his project or its product. So a worthy venture has been developed by a cooperative effort for the common good.

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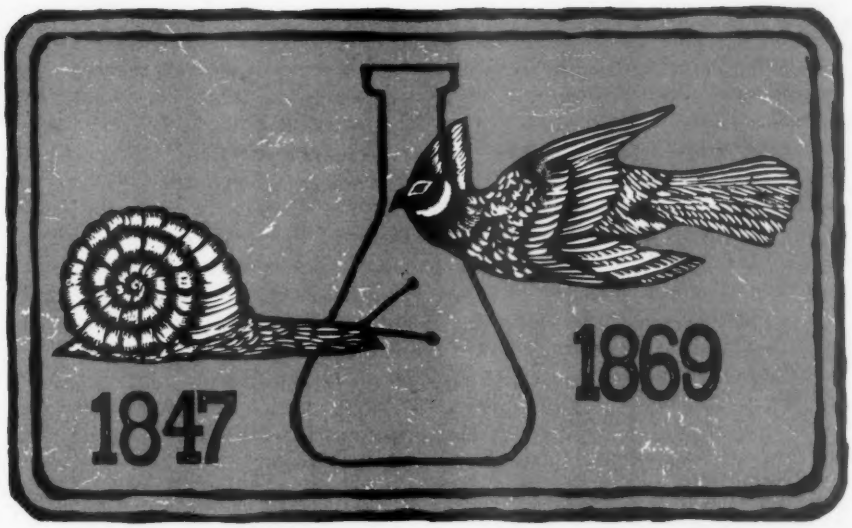


TRACE ELEMENT RESEARCH

Report of An International Symposium

OVER a century ago in Europe, several independent investigators showed that certain trace elements were present in living tissue. One of the first—copper—was shown in 1847 to exist in combination with the blood proteins of snails. Since then, the list of trace elements known to be physiologically important to animals has expanded at the rate of about one every decade.

Although man's knowledge of the role of trace elements in human nutrition has risen markedly in the past two or three decades, this whole area of research today is considered a frontier somewhat comparable to that of vitamins in the 1930's. This fact was undoubtedly contributory to the decision among leading trace element researchers to hold an international symposium on the subject late last year (Sept. 15–17).

More specifically, the symposium was designed to bring together scientists in the field to discuss and bring into focus certain trace elements that are candidates for being termed as "essential" nutrients, as well as provide newer information on some of the more established elements. The event was timed to introduce to the scientific community the new laboratory facilities of the Human Nutrition Research Division, Agricultural Research Service, U.S. Department of Agriculture, and to dedicate it to furthering the state of knowledge of mineral nutrition and metabolism for better nutrition in man.

Setting for the event was the campus of the University of North Dakota, Grand Forks, where the new laboratory is situated. Joint sponsors were the Agricultural Research Service, U.S. Department of Agriculture, and the University of North Dakota. Partial program support for the symposium was provided by Merck, Sharp, and Dohme (postgraduate program), Eli Lilly & Co., Mead Johnson Laboratories, and Proctor & Gamble Co.

HISTORY AND PHILOSOPHY OF TRACE ELEMENT RESEARCH

A particularly discerning review of the history and philosophy of trace element research was pro-

vided by Dr. E. J. Underwood, director of the Institute of Agriculture, University of Western Australia (Nedlands)—one of a score of distinguished participants in the symposium. Underwood's paper not only set the tone and scope for the entire program, but also gave the proper perspective for the significance of past research and the related, unanswered problems of today.

Underwood noted that trace elements were regarded as little more than scientific curiosities during the mid-1800's, and their discovery did little to stimulate studies of the possible wider significance of the component elements. It was not until C. A. MacMunn published his pioneer observations on iron and cell respiration in 1885 that the concept emerged that trace element-containing metalloenzymes are of profound importance to the functional integrity of the cells.

Underwood cited the work of the French botanist, A. Chatin, who, on the basis of his observations on the iodine content of soils, waters, and foods, concluded that the occurrence of goiter in man was associated with a deficiency of environmental iodine. No one knows what prompted Chatin to study iodine in this way, but two events are probably significant: (1) The discovery of iodine in abundance in seaweed ash by the Frenchman, Courtois, in 1811 and in sponges by the Scotsman, Fyfe, in 1819, and (2) the practice of the French physician, Coindet, of using salts of iodine therapeutically in treating goiter as early as 1820. (Burnt sponges were known to have been used successfully but quite empirically in the treatment of human goiter by the ancient Greeks.)

Certain anomalies in Chatin's data, Underwood noted, discredited his conclusions, and the iodine-deficiency theory lay almost forgotten for several decades until it was revived in this country during the early years of this century. But Chatin's work on iodine and the incidence of goiter was the first demonstration of an "area" problem involving a naturally occurring deficiency of a trace element. It was not until the 1930's, 80 years after Chatin's observations were first published, that it became evident that many other area problems, involving other trace element deficiencies and toxicities of geochemical origin, also existed in many parts of the world.

Underwood cited the technique of emission spectrography emerging in the 1920's as a means of determining the distribution of trace elements in biological materials, which gave a great stimulus to trace element research because it permitted the simultaneous estimation of some 20 to 30 elements in low concentrations.

Several features of the spectrographic distribution studies were commented on by Underwood. First, there was tendency to argue that the failure to detect a particular element in a particular tissue implied its absence, whereas in fact it could mean simply that the method was insufficiently sensitive. Second, some trace elements could not be quantitated at all by emission spectrography. (Arsenic, iodine, bromide, fluorine, mercury, and germanium are examples of such elements.) This fact obviously limited the usefulness of the studies. Finally, some workers were constrained to argue teleologically from their findings, to claim that a particular concentration in a particular organ or tissue was of itself evidence of function or purpose.

For instance, as long ago as 1919, V. Birckner stated "from its constant occurrence in the yolk of eggs, as well as in human and cow's milk, it is inferred that the element zinc exerts an important nutritive function, the nature of which is not yet understood." These proved to be prophetic words, Underwood observed, for the relatively high concentration of zinc in cow's milk was one of the factors influencing the Wisconsin workers to investigate originally the essentiality of zinc in mammalian nutrition in the early 1930's. Teleological arguments, he felt, can therefore be useful stimuli to further research, however misguided the reasoning may be.

Underwood paid tribute to the Wisconsin group led by E. B. Hart and C. A. Elvehjem who made the first major breakthroughs in research on purified diets. The demonstration of the essentiality of copper for growth and hemoglobin formation in the rat in 1928 came as a byproduct of their researches on iron. Within 3 years of this significant discovery, the Wisconsin group added a fourth trace element—manganese—to the list of essentials. They noted that mice and rats fed a milk diet supplemented with both iron and copper were infertile due to an impairment of ovarian activity and that reproductive performance could be restored by supplemental manganese.

These notable findings were made possible by the clever exploitation of a diet composed basically of cow's milk which in its uncontaminated state is naturally deficient in the three trace elements—iron, copper, and manganese. The third success of this prolific group at Wisconsin, the initial demonstration of the essentiality of zinc in mammalian nutrition in 1934, came from the use of the more conventional purified diet technique.

Underwood attributed the conspicuous success of the Wisconsin group to the heightened interest in trace element research at both the basic and the applied levels. The nutritional physiology of the trace elements soon became as fashionable and as profitable a field of study as that of the vitamins which had long dominated the nutritional scene and occupied so much of the brains and resources of nutritional science. Yet he noted the sobering fact that 20 years elapsed before any more trace elements were firmly added to the list of essentials and the purified diet approach once more yielded outstanding results. He referred, of course, to the work of Richert and Westerfield with molybdenum and that of Schwarz and Mertz, first leading to the identification of selenium as an essential element in 1957, and then to demonstrating a functional role for chromium in 1959.

Naturally-Occurring Area Problems

EQUALLY stimulating and even more economically-rewarding field studies of naturally occurring trace element deficiencies, toxicities, and imbalances came during what Underwood termed as "that remarkably productive decade—1930 to 1940." The motivation for these researchers was clearly economic: Field problems had to be solved if certain areas were to become, or to remain, satisfactory for the raising of livestock. Animals restricted to these areas failed to thrive or reproduce; they suffered from various debilitating diseases, with well marked clinical and pathological manifestations, and in many cases mortality was high.

He cited a number of successes in tackling applied problems during this period: In 1931 copper deficiency in grazing cattle was demonstrated in parts of Holland and of Florida and simple control measures were devised. In 1933–34, "alkali disease" and "blind staggers" of stock in parts of the Great Plains of the United States were established as signs of chronic and acute selenium poisoning, respectively. In 1935, cobalt deficiency was shown to be the cause of various wasting diseases of grazing ruminants in parts of Western Australia and South Australia. In 1937, enzootic neonatal ataxia of lambs in Western Australia was found to be caused by copper deficiency in the ewe, completely controllable by copper supplementation of the ewe during pregnancy. In 1938, excessive intakes of molybdenum from the herbage were revealed as the cause of a debilitating diarrhea affecting cattle confined to certain restricted areas in England and which could be controlled by massive copper therapy.

Mode of Action of the Trace Elements

DR. Underwood termed this early period as the "first golden era" of trace element research, when attention was centered on practical means of prevention and control. Little or nothing was known of the precise metabolic roles of the trace elements or of their specific functional relationship to the clinical and pathological disturbances in the animal that accompany deficiencies and toxicoses. He credited outstanding advances in the last decade as an outcome of collaborative studies by nutritionists, biochemists, pathologists, and enzymologists. He illustrated the extent of recent progress in this aspect of trace element research by reviewing briefly a few outstanding examples involving cobalt, manganese, copper, and zinc.

The Future of Trace Element Research

THE brilliantly successful research on the mode of action of cobalt, manganese, and copper, Underwood believes, serves to highlight our comparative ignorance of the basic biochemical lesions that lie at the root of other trace element deficiencies. Their very success, he says, points the way clearly to the need for similar types of investigations with other trace elements such as chromium, nickel, and tin. Identification of the mode of action of these elements in biochemical terms presents challenging and worthwhile problems for those scientists whose inclinations lie in trying to understand more about the basic roles of trace substances in living processes.

"It seems to me," the Australian authority observed, "that the pure scientist has other equally challenging problems in this branch of science. What

about all the other elements which occur ubiquitously in living matter? It seems very unlikely that only 10 or 11 of the scores of such trace elements that exist are essential to living organisms. It seems much more likely that the list of essentials will be lengthened as techniques improve and as the search continues. Perhaps the laboratory now being opened here in North Dakota will have the honor of extending this list and discovering further elements of physiological significance to man and animals."

Dr. Underwood suggested that it is not only the pure scientist who has the ball at his feet. The applied scientist with a different philosophy, whether human medicine and public health or animal health and production, should have ample scope for rewarding research with the trace elements.

"Public health problems involving environmental loading with elements such as lead, cadmium, and mercury are already causing concern in some areas, and yet we know very little indeed of the factors affecting the movements of these elements in the food chain from rocks and soils to animals and man through plants, air, and drinking water. We know still less about their possible long-term deleterious effects on man and the maximum intakes compatible with full physical and mental welfare."

He told symposium participants that man-made changes in the environment affecting the magnitude of the exposure to trace elements are "by no means confined to those resulting in the injection of large amounts of potentially toxic elements into the environment, important as these may be." He called for more attention to importance of technological changes in food production, processing and storage which might reduce intakes of nutritionally vital elements such as iron, zinc and chromium. The impact of changes in agronomic practices involving ever higher-yielding crop and herbage plant varieties and ever-higher applications of more and more concentrated fertilizers—these alone, he said, require constant investigation and surveillance.

"Applied research of this nature with a range of trace elements," he concluded, "could be of deep significance to the survival of man in a changing and challenging world. The philosophy of the pure and the applied researcher with trace elements thus emerges as fundamentally similar—the urge to know more of the environment in which we live. It is difficult to think of a more worthwhile, indeed a more noble, task."

BIOLOGICAL IMPORTANCE OF VANADIUM

A number of the symposium papers presented encouraging discussions on the possibility of other trace elements emerging as likely candidates for being physiologically essential to the health and well-being of man and higher animals. One of these elements is vanadium, and the discussant was Leon L. Hopkins, Jr., of the Human Nutrition Research Division of USDA's Agricultural Research Service.

Dr. Hopkins pointed out that although vanadium has not been established as physiologically essential, some evidence implies that it may be necessary for normal metabolism.

Vanadium has been found in noncarious human enamel and dentine, Hopkins noted, and reportedly promotes mineralization of teeth and bones and significantly reduces dental caries in rats and guinea pigs. He also cited research which indicates that vanadium (1) increases greatly the oxygen uptake of liver suspensions and (2) inhibits cholesterol synthesis.

Hopkins defined an essential nutrient as one which must be available in the diet since it cannot be synthesized by the organism or cannot be synthesized at a rate great enough to maintain health. Classically, nutritionists have established essentiality by reducing the level of the nutrient in the diet below the requirement of the organism. If fed for an adequate time, deficiency symptoms appear when contrasted to the control group receiving a supplement of the nutrient in question. Hopkins said this was the approach his laboratory has taken in trying to establish whether vanadium is or is not an essential element.

One factor that complicates nutritional research with vanadium is that symptoms of deficiency can be induced only by using a diet containing vanadium in the parts-per-billion range. Hopkins believes that researchers may have to move into the parts-per-trillion range for some elements.

Results of the USDA research study, as presented by Hopkins at the international symposium, show that vanadium is essential in the chick. The significant symptoms observed were slower growth in both the wing and tail feathers of chicks consuming

a diet containing 10 ppb vanadium. Analysis of tissues from these chicks indicated that they had been depleted of vanadium down to a level of a few ppb. Blood cholesterol levels of the deficient chicks were significantly lower than those of the control animals.

ROLE OF SELENIUM

A number of studies have shown that selenium is effective in preventing some but not all of the vitaman E deficiency diseases in laboratory and farm animals. Until very recently, however, every deficiency disease that responded to treatment with selenium could also be prevented by adding vitamin E to the diet. Proceeding from this base, Cornell University researchers set out to delineate more accurately the role of selenium. The Cornell studies were described by M. L. Scott of the university's Department of Poultry Science and Graduate School of Nutrition.

Three different vitamin E deficiency diseases are known to occur in chickens: (1) Vitamin E-antioxidant interrelated diseases; (2) vitamin E-sulfur amino acid interrelated diseases; and (3) vitamin E-selenium interrelated diseases. Dr. Scott stated that in all previous research with selenium in the nutrition of laboratory and farm animals, the nutritional effects of this element have always been related, in one way or another, with vitamin E nutrition. The Cornell team, therefore, sought to obtain evidence as to whether or not selenium is required in diets containing adequate levels of all known nutrients.

Experiments were conducted with selenium-depleted chicks fed a crystalline amino acid diet adequate in all known nutrients including high levels of vitamin E—but severely deficient in selenium. Results showed that a specific selenium deficiency causes poor growth, poor feathering, and fibrotic degeneration of the pancreas. Death usually occurs following markedly decreased absorption of lipids including vitamin E.

The pancreatic degeneration, Scott stated, results in a decrease in pancreatic and intestinal lipase which causes a failure in fat digestion. Under such conditions, bile flow is almost eliminated. When bile and monoglycerides are absent in the intestinal lumen, there is a failure of micelle formation which in turn impairs the absorption of vitamin E. Addition of bile salts to the diet did not return fat digestion to normal levels, and only temporarily enhanced vitamin E absorption. Addition to the basal diet of free fatty acids, monoglycerides, and bile salts improved the absorption of vitamin E and survival during the experimental period of 4 weeks, but did not prevent the degenerative changes in the pancreas. The Cornell study showed that the selenium requirement for preventing pancreatic degeneration depended on the vitamin-E level in the diet. With very high dietary vitamin E levels (100 IU per kg. or more) as little as 0.01 mg. selenium as sodium selenite per kg. of diet completely prevented pancreatic degeneration. However, when the vitamin E content of the diet was at more nearly normal levels (10–15 IU per kg.), 0.02–0.04 mg. selenium was required per kg. of diet.

Scott reported that exudative diathesis did not occur as long as some vitamin E was being absorbed. Exudative diathesis occurred only after the absorption of vitamin E was decreased to very low levels by the pancreatic degeneration. With the use of fatty acids, monoolein and bile salts which resulted in a marked improvement in vitamin E absorption, exudative diathesis did not occur even though the pancreas under these dietary conditions continued to undergo severe atrophy and degeneration.

As a result of these studies, Scott proposed the following scheme to depict the interrelationship between vitamin E and selenium in the prevention of both exudative diathesis and pancreatic degeneration:

1. When the diet contains adequate selenium, the integrity of the pancreas is preserved.
2. With the normal production of pancreatic lipase, fat is digested, and there is normal bile flow and normal formation of bile salt-liped micelles.
3. Micelle formation then allows maximum absorption and good blood levels of vitamin E.
4. Either vitamin E or the selenium in the diet will prevent exudative diathesis, but a good blood level of vitamin E also helps to preserve the selenium in the blood and tissues, thereby reducing the dietary level of selenium required to protect the pancreas.
5. Thus, vitamin E spares the selenium requirement and, conversely, selenium enhances absorption of α-tocopherol, thereby reducing the dietary requirement for vitamin E.

ROLE OF CHROMIUM

INTEREST in the role of chromium was particularly high at the symposium. Of the three papers presented, two of them are summarized herewith: "Chromium Metabolism—The Glucose Tolerance Factor," by Walter Mertz and Edward E. Roginski of the Human Nutrition Research Division, USDA's Agricultural Research Service; and "Chromium Nutrition in the Mother and Growing Child," by E. Michael Hambidge of the Department of Pediatrics, University of Colorado Medical Center.

Chromium Metabolism

IN setting the stage for his presentation, Dr. Mertz acknowledged the fact that although the physiological role of chromium is being increasingly recognized, our knowledge of chromium metabolism is incomplete. It is known, for example, that (1) trivalent chromium acts as a co-factor for the peripheral action of insulin, (2) that chromium-deficient animals and some human subjects respond to trace supplementation of this element, (3) that repeated pregnancies and diabetes are associated with lowered chromium concentrations in hair, and (4) that insulin-dependent diabetics metabolize chromium in a fashion different from that of normals.

Oddly, Mertz noted, less than half of the adult test subjects responded to chromium supplement with improved glucose tolerance. Attempts to obtain an immediate response in adults by giving higher oral doses were unsuccessful. He pointed out that these observations are in distinct contrast to the immediate effects seen after zinc or iron supplementation.

Mertz expressed the belief that the biological activity of chromium depends strongly on the chemical form of the complex of which the element is part. For example, brewers yeast incorporates chromium salts into one or more compounds that are much more readily available for placental transport and other functions than are the simple salts of the element. These fractions furthermore are of a much greater activity than simple salts in their potentiation of insulin *in vitro*. The compound responsible for this activity has not yet been chemically identified, Mertz said. However, it can be described by some chemical, biochemical and physiological criteria, and on this basis it is termed *glucose tolerance factor* (GTF).

After reviewing and commenting on a wide range of chromium-related research studies, Mertz observed that the data clearly demonstrate great quantitative and qualitative differences in the metabolism and biological effect of chromium, depending on the form in which it is bound. When the element exists in an organically bound form, such as in brewers yeast, liver, kidney, wheat, etc., it is absorbed better, has a different tissue distribution, and is available to the fetus.

All of the presently available evidence is consistent with the hypothesis that the chromium-containing substance occurring in brewers yeast and other natural sources is identical with the insulin-potentiating principle. Furthermore, the dependence of the biological action of GTF on the presence of insulin is the same as that of simple chromium salts. Mertz cautioned, however, that conclusive proof can come only by identifying the chemical structure of the compound.

"The problem of a classifying glucose tolerance factor in a nutritional sense is difficult," Mertz said. "Chromium is different from most trace elements in that it is not, like the others, easily built into its specific sites of action. The rat has a very limited ability to utilize inorganic chromium salts for placental transport. In man, the effect of supplementation with chromium chloride often takes weeks to appear, and this lag phase cannot be overcome by higher doses. But chromium is also different from cobalt which has an absolute requirement for a special organic binding. Monogastric mammals cannot synthesize vitamin B_{12}, but there are indications that they can synthesize the organic chromium compounds GTF, if only at a limited rate. It is not known whether this synthesis occurs within the organism itself or is a function of the intestinal flora."

Mertz told symposium participants that work is now in progress to prepare sufficient quantities of glucose tolerance factor for measuring metabolism and its effect on the impaired glucose tolerance in human subjects.

Chromium Nutrition in the Mother and Child

DR. Hambidge aptly summarized the status of chromium nutrition and detection of a deficiency

state in the individual subject by terming it "a challenging problem." He acknowledged that well-controlled therapeutic trials of chromium supplementation, with serial observations of the effects on glucose tolerance, provide a reliable test for chromium deficiency and also a measurement of the clinical sequelae of such a deficiency. However, he said, this approach is applicable only to small groups of subjects and it is very tedious for the patient—and especially difficult with the child and pregnant woman.

Although a more definitive discussion of chromium nutrition and malnutrition in the young must await further investigations, Hambidge believes the results suggest that spectrochemical analyses of chromium in readily available samples from the living subject are of value in detecting chromium deficiency in the individual young subjects who may be at a special risk stage from suboptimal chromium nutrition. For example, the exceptionally low-hair chromium levels in the postpartum woman, and perhaps the results of serum studies in the last month of gestation, indicate that pregnancy depletes maternal chromium reserves in the human as well as in laboratory animals. The extent to which this represents a health-hazard to the mother has not been clarified, Hambidge observed, but theoretical considerations together with the results of initial investigations of the gestational diabetic suggest that this depletion may have important clinical consequences.

In the child with insulin-dependent juvenile diabetes mellitus, the excessive urinary excretion of chromium observed in some patients supports the conclusion that chromium metabolism is abnormal. In the infant with protein-calorie malnutrition, chromium deficiency is one etiologic factor in the clinically important abnormalities of carbohydrate metabolism which complicates this disease.

Hambidge feels that the relatively poor supply of maternal glucose tolerance factor in premature deliveries—and apparently in some full-term neonates—may compromise their chromium nutritional status in later infancy and childhood. It remains to be determined, he said, whether the rapid "normal" decline in chromium levels in the first months or years of life is entirely physiologic. It cannot be assumed that tissue chromium concentrations within the normal adult range necessarily indicate optimal chromium nutrition for the growing child.

INTERACTIONS IN NUTRITION

THE growth in the knowledge bank of nutritional topics has markedly heightened the interest in the interactions of nutrients; that is, the effect of the level of one nutrient upon the availability or utilization of another. As the principal symposium speaker on this topic, Dr. D. M. Hegsted, Department of Nutrition, Harvard School of Public Health, expressed the conviction that these interactions will become increasingly important as more knowledge of trace element nutrition is acquired.

One of the factors that makes the study of nutrient interactions difficult, Dr. Hegsted noted, is that elements occur in foods in many different forms. This may or may not be significant depending upon what happens in the gastrointestinal tract or elsewhere in the body. It may not be very useful to determine what forms these are, since their modification after they are prepared and eaten may be a more important factor in determining their utility.

For example, he noted, much of the niacin in certain foods is in a bound form that is unavailable to several, perhaps all, species. The net result is that the voluminous food tables in which the content of "niacin" is given may border on nutritional rubbish. It is not certain whether it is even worth calculating the niacin content of a diet from these data. The situation with regard to folic acid is perhaps even worse, Hegsted observed. Total dietary iron is similarly of doubtful practical utility and the same may be true of zinc, selenium, chromium, and others.

Hegsted said many nutrient interactions seem to have some generalities—that is, diets high in phosphate inhibit the utilization of calcium, magnesium, iron, zinc, and probably all nutrients which have relatively insoluble phosphates. The same is true with phytate. He pointed out that this reference to the solubility of phosphates is only a logical "explanation" of what is often observed—it has rarely, if ever, been actually demonstrated to be the "cause" of the poor utilization.

Another factor that complicates the study of nutrient interactions, Hegsted explained, is the massive effort and formidable data problem involved. If, for example, three nutrients are to be

studied, it would require 125 groups of 625 animals; with four nutrients, 625 groups and 3,125 animals—assuming 5 levels to be investigated with 5 animals at each level of nutrient. The easiest statistical approach would be to assume that there are linear dose-response relationships, but Hegsted said he was certain that this will rarely, if ever, be the case. A purely empirical approach seems even less likely to provide solutions.

"We can at least dimly visualize the complexities of the gut," he reasoned, "and most interactions of minerals probably have an explanation at this level. However, the trace elements can be assumed to function primarily as catalysts and thus many metabolic adaptations can be assumed to offer possibilities for variations in requirements or functions of the trace minerals."

Hegsted cited another area of dietary interaction where numerous examples can be given but where very few can be quantitated or explained: the relationships between diet and toxicology. Diets high or low in fat, protein, or of differing composition modify the toxicity of hydrocarbons, insecticides, carcinogens, radiation, antioxidants, etc. Again, he said, the data appear as empirical examples. With the great public concern in this area and particularly the increased effort that will undoubtedly be put into animal testing, he felt some serious effort should be put into this field. "What is the value of many of the long-term feeding trials if one can modify the outcome by selecting the proper diet before the feeding trial is set up?" he asked.

Like Underwood, the Australian specialist, Hegsted emphasized the potential problems that may arise because the national food supply is changing so rapidly, particularly in the direction of more highly processed foods and convenience foods. The first, he said, may or may not have compositions similar to more generally recognized foods; the latter impose limits on the consumer in selecting nutrient intakes. He felt it is almost certain that we shall move toward more general fortification programs in the near future. He sensed a danger in this, since interest will be focused upon the traditional nutrients—the vitamins and minerals of concern over the past 30 to 40 years.

"We must be aware that unless attention is paid to other nutrients, including the trace elements, we may be producing undesirable changes," Hegsted warned. "We must stimulate more work on the surveillance of the national food supply in terms of all nutrients and improve our methods for keeping track of the nutritional status of the population with regard to all nutrients. In those areas where we are relatively ignorant, as with the trace minerals, the problem may be more serious than we know."

Dr. Hegsted concluded by citing the frequent complaint that biochemists are continually involved in dissecting the cell into smaller and smaller systems but that few are concerned with putting these back together again so that the metabolism of organs or whole organisms can be interpreted or predicted. Similarly, nutritionists have of necessity worked toward more and more simple purified diets where everything in the diet is under control. The need for this, he said, is obvious and nowhere more evident than in the study of trace minerals. However, he cautioned nutritionists to bear in mind that the findings under these conditions may have little practical significance, and that they must not forget that an ultimate objective is an explanation of what happens in a more real and complex world.

* * *

The fact that the 1970 International Symposium on the Newer Trace Elements in Nutrition raised more questions than it answered was probably not unexpected. Thus, the symposium served two functions in admirable fashion: (1) Providing an open forum in which research leaders in the field could share their thinking, and (2) providing an impetus for a long-range research program in which the new USDA laboratory can and should play a dominant role—at least in North American efforts, if not worldwide.

From the consumer standpoint, one of the healthy signs is that the food-processing industry is taking more notice of the discovery trends in trace element research. Therefore, it seems reasonable to expect that processed foods will more and more reflect an awareness of the essentiality of certain elements for good health and well-being. Satisfactory mineral nutrition status has too long been taken for granted in the past. The international symposium has clearly helped to provide the focus needed for stepped-up efforts in this area of research.

SCIENCE NOTES

SUNFLOWERS MOVING UP

Since 1962, sunflower oil has climbed from fifth to second place on the international oil market—thus increasing faster in importance than oil from any other source. The popularity of this oil is due to its attractive color, pleasant flavor, good stability, high smoke point and high linoleic acid content which helps decrease blood cholesterol.

Chemical, physical, and taste tests show that dehulled sunflower kernels can be used in human food formulations, such as a nut substitute in baked goods and candies. High protein tortilla chips and textured vegetable protein fibers made from sunflower meal were quite acceptable.

Native to Texas, sunflower could replace declining cotton acreage and provide a raw product for cotton seed crushing mills.—*Texas AES Annual Report.*

Tribulus terrestris, a weed found in Lebanon, earned its common name—puncture vine—from the fact that its fruit spines can puncture hides of cattle and automobile tires.

TECHNICAL JARGON

Forms of communication are changing so rapidly today that many of the traditional notions about readability may no longer be appropriate.

Research has shown that words of the space age are accepted readily as long as they have singular meanings. But a word that has many possible meanings may cause considerable confusion.

The mass media have contributed much to this improved public understanding. Television, particularly, has had a clear impact on the vocabulary of children—as do the more complex elementary school texts. As understanding rises, people are able to deal with more complicated ideas.—*Minnesota Science 27:1*

The number of cases of bacterial food poisoning in the United States from Clostridium perfringens has increased 8,000 percent in the past 10 years.

SLUDGE AS FERTILIZERS

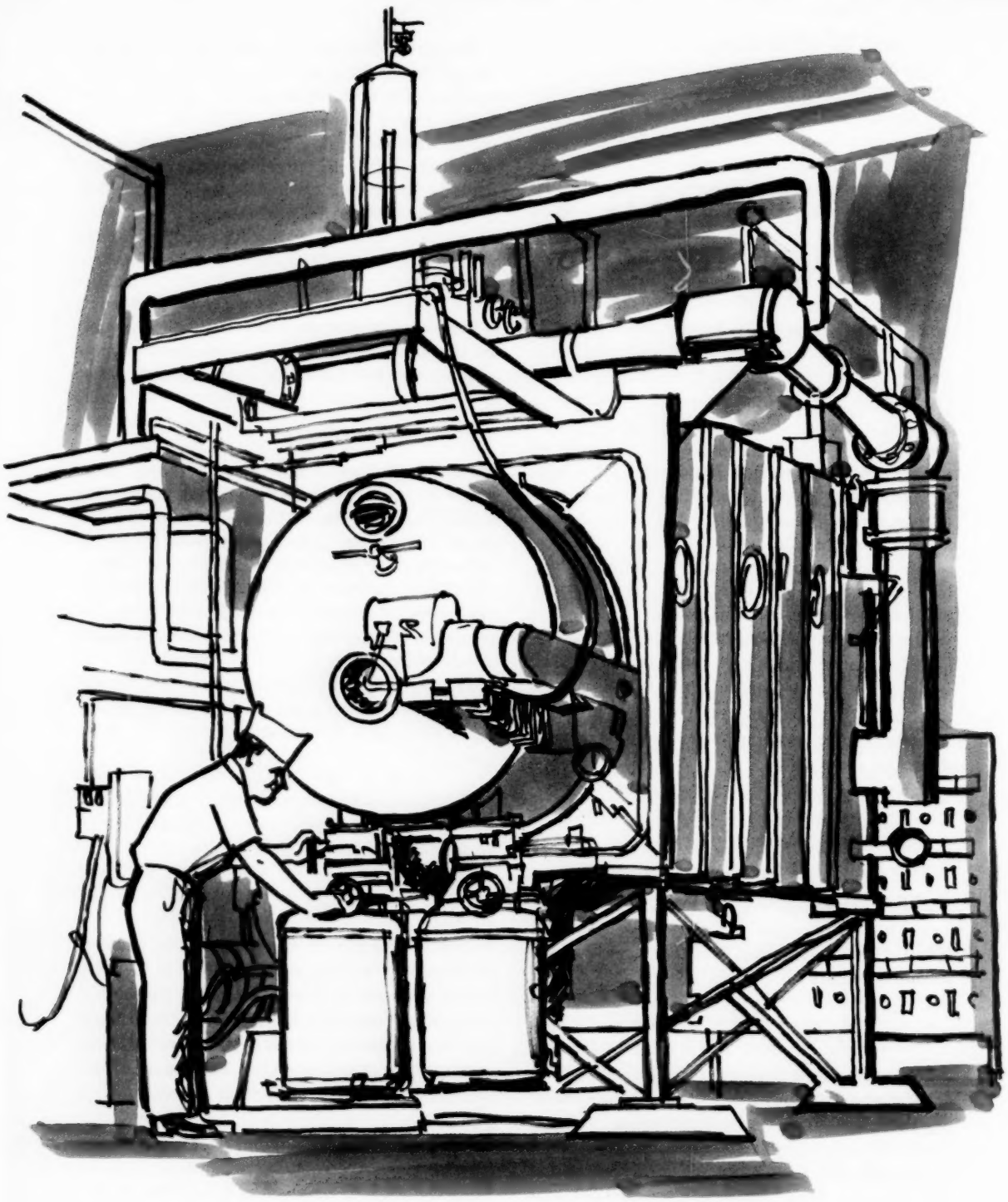
Four years of research by the Metropolitan Sanitary District of Greater Chicago has shown that digested sludge (human wastes) can be used beneficially to revegetate barren land and even to fertilize cash crops. No immediate or cumulative evidence of soil, plant, or human hazards was observed. Water quality studies on sludge-fertilized fields showed no change in phosphorus and a reduction in heavy metal concentrations.

This recycling of material from waste water treatment plants is viewed as a means of reducing air and water pollution by cities.—*Soil Science Society of America*

Tests in six states last winter showed no toxic effects from feeding blighted corn to pigs and little or no difference in gain and feed efficiency.

TIDINGS OF ANTIQUITY

The 108-year-old Parrott Hall, original building of the New York Experiment Station at Geneva, will soon become an Historic Site under the control of the New York State Historic Trust. Alternately used as a farmhouse, bachelor hall, office building, and lab, plans are to use the historic structure as an agricultural museum.—*N.Y. Food & Life Sciences Quarterly*



VACUUM FOAM-DRIED WHOLE MILK

A Success Story in Cooperative Research Effort

H. I. SINNAMON AND N. C. ACETO

EVER since the early 13th century, efforts have been made to facilitate the storage and transport of milk by removing its water content. Marco Polo reported that a form of dry whole milk was used by the soldiers of Genghis Khan as part of their rations (*13*).[1] Although numerous attempts have been made since that era to produce a satisfactory dry whole milk, documentation of the methodology used did not appear in the literature until the 19th century. According to the technical and patent literature, technicians and chemists were trying to devise suitable methods for making a good dry whole milk throughout most of that century. The degree of success of these ventures can be inferred from the comment of Fleischmann, a noted German dairy scientist, who indicated in 1901 that it would not be possible to produce a marketable dry whole milk worthy of the name (*13*).

Despite Fleischmann's discouraging pronouncement, work has continued on the problem to this day. Two factors have served as strong incentives to carry on further research: The desirability of lengthening the storage life of milk, and the seemingly wasteful occupation of carting around the country enormous volumes of liquid that contains more than 80 percent water.

During the 1950's, research on the problem intensified considerably—chiefly because of the impetus received from the development of successful methods for making dry skim milk. It appeared that these newer technologies might be adaptable for making an acceptable dry whole milk product. The assignment to tackle the problem in earnest was given to chemical engineers at the Philadelphia laboratory of the Department of Agriculture's Eastern Utilization Research and Development Division in 1955. What followed was more than a decade of painstaking research effort alternately marked by temporary setbacks and rewarding breakthroughs that ultimately led to an economically feasible process for making a dry whole milk of good quality. This article tells the story of that research effort—in somewhat abbreviated form, of course, because of space limitations and an attempt to maintain some degree of continuity.

[1] Italic numbers in parentheses refer to Literature Cited, p. 41

The Background

AS mentioned above, previously developed methods for making a marketable dry skim milk provided a good starting point for modern research on making a satisfactory dry whole milk. Two methods are currently used in manufacturing the skim product—spray drying and roller drying. Of the two, spray drying is the more important (*4*) because it provides, through certain modifications, the means for obtaining "instant" dispersibility—that is, the ability to dissolve quickly in water with a minimum of stirring. These modifications of the spray-drying method were developed since World War II, and because of further refinements of the process, dry skim milk has become a successful product of commerce.

Instantizing techniques, however, have not been suited to dry whole milk (*14*). From a flavor standpoint, too, major problems arise when drying whole milk that are absent in the case of skim. Dry whole milk made by earlier methods has been described as (*a*) very difficult to disperse (particularly without using warm water), (*b*) inclined to taste highly cooked and "eggy," and (*c*) deteriorating during storage to flavors such as tallowy, rancid, stale, burnt feathers, etc. (*15*).

This was the state of the art when the present work was begun in the Department of Agriculture. The objective of our research was to develop a commercially feasible process for the preparation of a beverage-quality dry whole milk that would disperse easily in cold water, have the flavor of fresh whole milk when newly prepared, and maintain those properties for a reasonable time in storage (6 to 8 months at 40° F).

Development of the Batch Process

BECAUSE of the poor quality of the dry whole milks available when this work began, the first problem seemed to be to determine if it would be *even possible* to produce a dry whole milk of the desired good flavor and easy dispersibility. In the usual drying practice, fresh flavor was lost by "forewarming" the milk—that is, subjecting it to high heat before the actual drying process. Forewarming was thought to be necessary because it either (*a*) produced natural antioxidants needed to combat fat oxidation during spray drying and storage, or (*b*) destroyed the oxidizing enzymes present in milk (*13*). But because the treatment also imparted a cooked flavor to the milk, we decided to eliminate this step if possible.

Another obvious way to avoid oxidation during drying was to dry under vacuum. Vacuum drying also appeared to offer rapid dispersibility through "puff-drying," a technique in which a highly expanded, sponge-like structure is created by water vapor bubbles as they form in a liquid concentrate during vacuum drying. Puff-drying had produced dry fruit juices that dissolve rapidly in water (*20*). For these reasons, puff-drying techniques were used in the first attempts to produce a satisfactory dry whole milk. These experiments were carried out in a vacuum shelf dryer.

Puffed structures can be developed by various devices, and for materials which are readily soluble the type of structure may not be of prime importance for rapid dispersibility. With whole milk, however, the structure markedly influenced the dispersibility rate of the dried product.

Two possible structures are illustrated in figure 1. The puffed form on the top was developed during

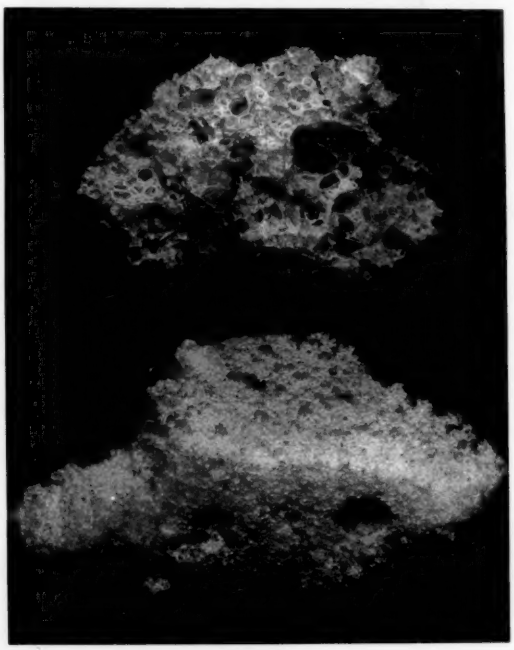


FIGURE 1.—Structures obtained by water vapor (top) and entrained gas of low solubility (bottom).

vacuum drying by boiling off the water vapor from a degassed concentrate—that is, one containing no trapped air or oxygen. The large, nonuniform bubbles had a heavy, tough, intercellular structure, and dispersed very poorly. The puffed product on the bottom was formed by the expansion of the low solubility trapped nitrogen gas in the concentrated milk as the pressure in the dryer was reduced. This form has small, uniform bubbles and a fine, fragile, intercellular structure. This new, desirable form was called "foam" (*19*).

Further experimentation showed that the mere use of an entrained (trapped-in) gas does not insure a form that will disperse readily. In order for entrained gas to be effective in forming a fine-grained foam as pressure is reduced, the concentrate must be held at a low enough temperature to allow the entrained gas to expand sufficiently *in situ* to form the foam before the pressure in the dryer reaches the flash point of the concentrate. If the flash point is reached first, the concentrate will boil, removing the entrained gas. The resulting structure will then be the form caused by bubbles of water vapor in a degassed concentrate (*19*).

Much of the research effort that went into the development of a satisfactory batch process was guided by scientific intuition—a characteristic of a research worker that quite often brings rewarding dividends. It should be pointed out here also that our chemical engineering research team was primarily skilled in the basic principles of drying heat-sensitive liquid materials; we knew much less about milk *per se*. In the daily laboratory procedure, which continued for nearly 4 months, various modifications had to be proved as being practical and feasible or else unrealistic for our purposes. After the 43d batch had been run, it appeared that the process had finally been perfected to the degree deemed necessary for moving to the next step.

In the flow diagram for the batch process as finally developed (fig. 2), fresh pasteurized, homogenized milk is concentrated to about 48 percent solids content at 90° F in a high vacuum, falling-film evaporator. It is then heated to 135° F and homogenized, first at 4000 psi and then at 500 psi, in a single-stage homogenizer of the pulsator type. Immediately prior to homogenization, nitrogen is bubbled through the concentrate, dispersing entrained gas through the material. The concentrated

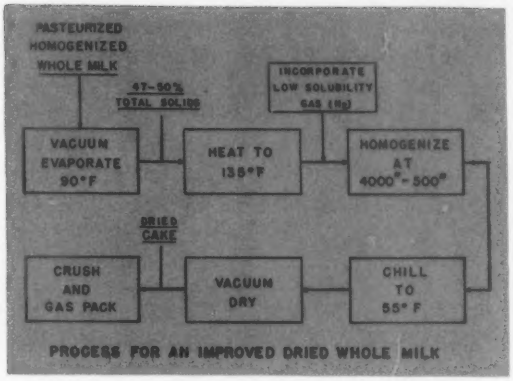


FIGURE 2.—Flow diagram for batch process.

milk is then flowed over stainless steel drying pans to an average depth of 1/16 inch, chilled to 55° F or below, and dried as a foam in a vacuum shelf drier. The resulting dried mass is crushed lightly through stainless steel screens.

In vacuum foam-drying, two separate phenomena occur sequentially under vacuum. In the first the foam is created, and in the second the foam is dried. In puff-drying, on the other hand, the puff is formed during and as a result of the drying proper.

Need for Testing

ALTHOUGH the product resulting from vacuum foam-drying appeared to be what we were looking for, it needed to be thoroughly tested for dispersibility and other factors. Screening the foam through 20-mesh resulted in more rapid dispersing but a more bulky product than screening through 40-mesh. Dispersibility of the product was unimpaired after a year's storage at 73° F, but deteriorated at 100° F. Forewarming resulted in a more rapid loss of dispersibility during storage at 100° F, and there was no apparent improvement in flavor stability (*10*).

Storage studies also showed that with oxygen present in the container at 73° F, the product stored best if the moisture content was between about 2.8 percent and 5.1 percent (*2*). Very important findings for the future work were that the 5-hydroxymethylfurfural content (an intermediate product in the browning process) of the freshly-dried product could be used both as a measure of the heat treatment undergone during processing, and as an in-

dicator of the future storage stability of the product (*5*). These findings were so important that research was carried out on the method of analysis (*9*).

Development of the Continuous Process

THROUGHOUT all phases of our research on developing a dry whole milk, we had to keep constantly in mind the objective of quality. The high standard arbitrarily set accounts in part for the months of effort devoted to measuring all aspects of the batch output. When the product aspect of the objective was satisfied by the development of the vacuum foam-drying process, the next problem was to determine whether the process was economically feasible on a commercial scale. An economic analysis by our cost engineers showed that the batch process was too costly to be of commercial significance, so an integrated pilot plant was designed and built for the translation of the batch process to a continuous one (*1*).

An apparent potential of continuous vacuum drying of whole milk not found in batch vacuum drying or conventional air drying was that it may be possible in a continuous vacuum operation to dry, handle, and package the milk with virtually no contact with oxygen once the milk enters the processing lines. If this could be accomplished, oxidation might be eliminated as the major off-flavor problem that had long plagued the dry milk industry. Thus, the continuous operation was designed to integrate all phases of the manufacturing process including packaging so that the milk would not be exposed to more than trace amounts of oxygen from the time it entered the pasteurizing line until the consumer opened the package containing the dry product. Later experimental evidence showed that the continuous process had successfully simulated an oxygen-free process, and that this in turn had eliminated oxidation as a major off-flavor problem (*3*).

In the continuous process, raw whole milk is adjusted to 26 percent fat content (milkfat basis), pasteurized and homogenized according to accepted practice, and then concentrated in a single-pass, agitated falling-film vacuum evaporator to a constant apparent viscosity. Milk is introduced at the top of the evaporating section, and flows down the inside wall of the evaporator body while steam for evaporation is maintained on the outside wall. The four blades of a rotor turning inside the body and clearing the inside wall by 1/32 inch spread the milk into a thin, turbulent film across the whole inside wall of the evaporator, thus providing highly efficient conditions for evaporation. In a descent of only 23 inches, the milk is evaporated at a high rate from 12 percent to 45 percent solids content. Viscosity is the control variable because it is a prime factor contributing to the formation and stability of fluid foams, and because in milk concentrates, viscosity and solids content do not correlate well from one batch to another.

Next, the concentrate is homogenized in a two-stage, single-pass, variable rate homogenizer operating at 3000 and 500 psi. The function of the second homogenization is to eliminate "oiling off" of the reconstituted milk. This treatment also reduces substantially all of the fat particles to below 2 microns in diameter. The homogenizer also acts as a pump that maintains the concentrate flow rate for gas dispersion. Nitrogen is metered into the concentrate stream just ahead of two scraped surface heat exchangers that simultaneously chill the concentrate to about 35° F and disperse the nitrogen to a bubble size of less than 75 microns. The gas-containing concentrate is then delivered to the dryer through a metering pump.

The key piece of equipment in the pilot plant is the continuous vacuum dehydrator. The dryer consists of an endless solid stainless steel belt 12 inches wide which alternately passes over heating and cooling drums. Drums are 2 feet in diameter and are spaced 9 feet between centers. Either vacuum or pressure steam can be supplied to the heating drum, and coolant at various temperatures can be circulated through the cooling drum. Heat can be applied to either side of the belt between the two drums by means of banks of individually controlled electrical radiant heaters. The whole apparatus is enclosed in a chamber where pressures can be maintained from 50 to 0.5 mm Hg absolute.

The gas-containing concentrate is then metered to the dryer through a feed line which is jacketed by a cooling pipe. The feed temperature is adjusted to be below the flash point when it enters the drying chamber. Nitrogen in the concentrate expands in the nozzle and the resulting foam issues as a thin, uniform blanket or film. The belt carries the foam through the drying zones, where the moisture is

removed, to an oscillating doctor blade that removes the dry product from the belt. The product drops into a chute, then goes to a screw conveyor which carries it to one of two receivers.

Reducing the Cost

THE work described above was a faithful translation of the batch process. An economic evaluation indicated that it, like the batch process, was too costly. The study further indicated that reduced costs could be obtained by reducing the bulkiness of the product as well as by increasing the dryer output, since packaging costs are lower for less bulky products. Thus, research was begun to seek changes in the continuous process in the interest of economy that would have little or no effect on product quality. The answer was found in a technique called "boil-down" (*16*). Just as in many other steps in our research and development process, the advice of cost engineers on the laboratory staff was the determining factor at this point as changes and improvement were considered, tried, and tested.

It is a generally valid proposition that thinner films provide higher rates of heat and mass transfer, so a reduction in foam thickness appeared desirable. We had learned, however, that at 3 mm Hg absolute dryer pressure, the thickness of the foam blanket reached a minimum at a nozzle opening of 0.047 inch (*1*) and that at smaller openings the foam blanket became thicker. Thus, foam thickness could not be reduced further by manipulating the nozzle. It would be necessary to somehow destabilize the foam structure once it had been applied to the belt. This was accomplished by raising the pressure in the drying chamber from 3.0 to 19.0 mm Hg absolute. At 19 mm, the foam structure partially broke down under the influence of heat ("boil-down"), leaving a thinner film. The increased chamber pressure that caused the foam to be only partly stable increased the output of the dryer by 43 percent and doubled the density, thus leading to lower production and packaging costs. This was gained, moreover, with a slightly improved quality due, no doubt, to the decreased drying time.

The Foam Stability Problem

ALTHOUGH the "boil-down" technique improved the economic picture, we were then faced with the problem of having no methodology for studying the properties of concentrated whole milk foams and characterizing their stability. Therefore, apparatus was developed for measuring two independent parameters—foaming ability and foam stability. Foaming ability is the initial height of a foam immediately after its formation in a column developed for the test; foam stability is the rate at which the foam subsides. We learned that the foaming ability of milk concentrates can only be described by a complex function of viscosity and temperature; that foaming ability reaches a minimum at about 70° F; and that the rate of foam subsidence can be described by an inverse exponential function of viscosity alone (*11*). The ratio of foaming ability to foam stability was a measure of foam behavior that could be used as a parameter in later mathematical studies of the process (*6, 7*).

In addition to the complex response of milk concentrate foams to viscosity and temperature, we observed that the behavior of concentrates was also affected by a seasonal influence (*16*). In winter the foams were relatively unstable, in summer they were relatively stable, and in spring and fall they

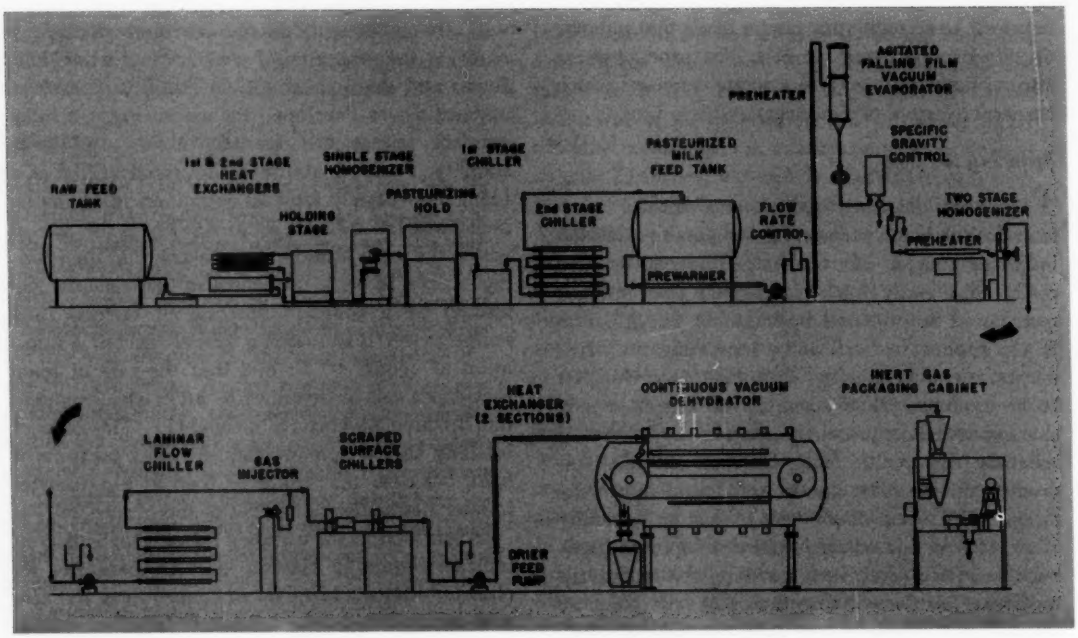


FIGURE 3.—Pilot plant for vacuum foam-dried whole milk.

passed through transitional periods of stability. Such behavior was undesirable, because the least extreme would cause the process to be non-reproducible on a year-round basis, and at the most it would even cause the process to be unworkable during part of the year. Research was therefore necessary to either determine the cause and cure of this effect or to show how to compensate for it.

After three years of intensive research effort, our results showed that the concentrations of all the whey protein fractions except β-lactoglobulin varied with season in direct proportion to the foam stability. β-lactoglobulin concentration had no seasonal trend (*8*). It was further found that the phospholipid concentration of the milk also varied seasonally, being in inverse proportion to the foam stability (*12*). These results suggested that foam stability could be increased by adding whey proteins, or decreased by adding phospholipids. Since a relatively unstable foam was desired, work was directed to the addition of a phospholipid, which in our case was soy lecithin.

The simplest procedure for year-round plant operation would be to determine one concentration of lecithin to be added throughout the year. Since the naturally-occurring phospholipids of milk varied seasonally in concentration, one single, year-round concentration of lecithin would be possible only if the naturally-occurring variation in foam stability could be overridden. Earlier research showed that foam stability was related to viscosity (*11*). This fact was used to solve the dilemma—the natural phenomenon was overridden by increasing the viscosity through an increase in solids content of the concentrate to such a degree that the foam was stable all year round. Then, uniform instability all year round could be accomplished by adding a single ratio of lecithin to milk solids.

Attaining Consistent Quality

ONCE the foam stability problem had been solved, we directed our attention to improving the drying process so that the best product quality would be consistent with a high output. Thirteen independent variables were identified and seven dependent variables were originally selected to describe proc-

ess efficiency and product quality. The study was carried out over a 3-year period using experimental designs and mathematical model simulation. Prior to the study, it was assumed that if moisture and HMF content were within acceptable limits, the other dependent variables would be also. This proved to be largely correct (*6, 7*). Although the study was terminated short of completion, a series of 42 runs based on the predictions of the study showed that the process was successful.

As finally developed, this pilot plant (fig. 3) was used to produce a quantity of vacuum foam-dried whole milk—6,600 quart-unit packages—sufficient to support a limited market study in the Lansdale, Pennsylvania area (*18*). The milk was packaged under nitrogen in cans containing the equivalent of one quart of fluid milk, labelled "Dairy Fresh," and sold from the dairy cases of 9 supermarkets over a 12-week period. The milk was priced 4¢ below the store price of a quart of fluid milk. A cost estimate showed this to be a reasonably profitable figure (*21*). Even though it was a new item, the product sold well, indicating a good potential for commercial success. Consumer acceptance was high. Purchasers reacted very favorably to the flavor, dispersibility, storage convenience, cost, and richness of the dry milk. A great majority of them considered it as good as or better than fresh whole milk on all factors (*18*). An interesting finding was that the sales of Dairy Fresh seemed to have no effect on the sales of other dairy products. Apparently Dairy Fresh was purchased for special uses, thus signifying an additional market for milk.

* * *

This research program, which culminated in the successful development of a high quality dry whole milk, exemplifies what can be accomplished when scientists of different disciplines work cooperatively toward a common goal. By the time that research and development activities on the project had drawn to a close, the roster of active participants included chemical and mechanical engineers, chemists, food technologists, micro-biologists, statisticians, and economists. With a few exceptions, the list of authors in the literature cited section represents those who deserve credit for significant contributions to the work.

One point that deserves further emphasis here is that every single phase of the research project was planned and executed with an awareness of the practicality of the whole venture. In other words, our team realized that nothing could be gained unless the methodology was economically feasible. The final economic evaluation, based on calculations for a full-scale operation, showed that this goal was reached. Dairy Fresh *can* be manufactured the year round and sold at a profit. Although no attempt was made to evaluate the potential of the Dairy Fresh market, some indications can be gleaned from the high ratio of favorable consumer reactions in the market study (*18*). This response is no doubt reflected in the interest currently being noted in the dairy and food processing industries for manufacturing a dry whole milk similar to the Philadelphia product.

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THE AUTHORS

FRANK G. VIETS, Jr. ("The Mounting Problem of Cattle Feedlot Pollution") is research soil scientist and leader of soil fertility investigations, Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Fort Collins, Colo. He earned a B.S. in 1937 at Colorado State University, M.S. at the University of California, Davis, in 1939, and a Ph. D. at Berkeley in 1942. He did research and supervised production of human blood plasma fractions and penicillins during World War II at Cutter Laboratories, Berkeley, and then served as associate agricultural chemist at the South Dakota Agricultural Experiment Station. In late 1945 he joined the USDA research staff at Prosser, Wash., to do soil fertility research for the new Columbia Basin Project. In 1954 he was transferred to Colorado where he has conducted and supervised research on soil fertility, plant nutrition-water relations, microelement deficiencies, and environmental pollutants of agricultural origin in western states. Dr. Viets has handled special assignments in many foreign countries for USDA and served as visiting professor at Iowa State University and the University of Illinois. He has been editor-in-chief and president of the Soil Science Society of America.

R. A. BUCHANAN ("Australian Milk Biscuit") is senior research scientist, Division of Dairy Research, Commonwealth Scientific and Industrial Research Organization (CSIRO), N.S.W., Australia. He earned his B. Agr. Sci. from Massey Agricultural College, University of New Zealand. In 1959 he was granted a Rotary Foundation fellowship and a Fulbright travel grant to study at Iowa State University where he received his M.S. degree. Dr. Buchanan completed his Ph. D. when he was awarded a CSIRO studentship award to study for 2 years at the Rothamsted Experimental Station, University of London. He spent 3 years with the Victorian Department of Agriculture as an extension officer and a year with a co-operative dairy company before joining CSIRO in 1963. Dr. Buchanan is a member of the Australian Society of Dairy Technology and the Science Club in the National Science Center. His chief interest is in new outlets for butterfat and novel and conventional high-protein foods designed for underdeveloped countries.

ROBERT M. ALEXANDER ("Social Aspects of Environmental Pollution") is Director of the Air Resources Center and Water Resources Institute, Oregon State University. He received his B.S. degree from Oregon State College and M.A. from Harvard University. He was an assistant to the Director at the Oregon State Agricultural Experiment Station from 1946–48. In 1948 he joined the U.S. Department of Agriculture as an economist and worked in that capacity until his appointment in 1950 as assistant director, Oregon State Agricultural Experiment Station. He was appointed to his present post in 1968. He was awarded a fellowship at Harvard University from the U.S. Public Health Service in 1967. Mr. Alexander is a member of the Legislative Task Force on Pollution and the Governor's Council for Environmental Science and Technology. He has authored several papers on environmental pollution.

HOWARD I. SINNAMON ("Vacuum Foam-Dried Whole Milk") is head, Animal Products Investigations, Engineering and Development Laboratory, Eastern Marketing and Nutrition Research Division, ARS, USDA, Wyndmoor, Pa. He received his B.S. degree in chemical engineering from the University of Pennsylvania and his M.S. from Drexel University. He worked as a research fellow with the Sugar Research Foundation for a year before joining EMNRD. In 1952 he joined the Engineering and Development Laboratory in Wyndmoor as a research engineer. He was appointed head, Unit Operations Investigations, in 1960 and held that position until his present appointment in 1967.

NICHOLAS C. ACETO ("Vacuum Foam-Dried Whole Milk") is chief, Engineering and Development Laboratory, Eastern Marketing and Nutrition Research Division, ARS, USDA. He received his B.S. in chemical engineering from Villanova University, and following military service in World War II, he joined the staff of the Engineering Laboratory at Wyndmoor in 1946. In 1955 he became head, Animal Products Engineering Investigations, and in 1967 was appointed to his present position. He was a member of a group receiving the USDA Superior Service Award in 1955. Mr. Aceto is a Fellow of the American Institute of Chemists. His chief research interests are in product and process development.

Editorial Homework

Since the founding of *Agricultural Science Review* eight years ago, the editorial staff has from time to time found itself involved in matters far removed from routine editorial procedures. In the interests of learning more about the subject matter discussed in our articles, we've peered into microscopes, tramped through corn fields, tested pesticides, visited sugar refineries, tinkered with computers, counted blackbirds, looked at the stars, inspected dying lakes, listened to exciting lectures, suffered through dull ones, interviewed brilliant scientists, turned off lackluster ones, chatted with dirt farmers, munched new apple varieties, and fell asleep in libraries. The list could go on and on.

Now, with this issue of *Review,* we can add two new experiences to the list: baking a batch of Australian biscuits and whipping up a milkshake out of water and a strange new powder.

Two of the authors whose articles appear in this issue—R. A. Buchanan and H. I. Sinnamon—were kind enough to furnish the editorial office with samples of their scientific and technological achievements. Being an experimentalist at heart, we carted the stuff home and proceeded to turn the family kitchen into an organoleptic laboratory.

The item from Australia was a can of calcium co-precipitate—key ingredient in the milk biscuit. So, armed with a family-size recipe which the author had also supplied, we assembled the other necessary ingredients and proceeded to sift, measure, stir, knead, and roll—while from time to time pondering bits of unsolicited advice from a tolerant bystander. Two hours later, amidst a clutter of well-used "laboratory" equipment, we proudly surveyed the results.

Our product looked like Australian milk biscuits (they were round) and we like to think they tasted as they should (a distinctly foreign taste). But everyone seemed to like them, and we noted happily that a few of them quickly induced a state of satiety—just as they did at tea time in Australia.

The other item in our experimental kit was a can of vacuum foam-dried whole milk (Dairy Fresh) from the USDA Philadelphia laboratory. Oddly, this powder looked very much like the co-precipitate, but demanded much less technological skill in creating the finished product—even less bother than stirring up a cup of cocoa. It was a good drink—fresh and satisfying—and together with a couple of biscuits made a delightful snack for a weary editor who had finished another homework assignment.

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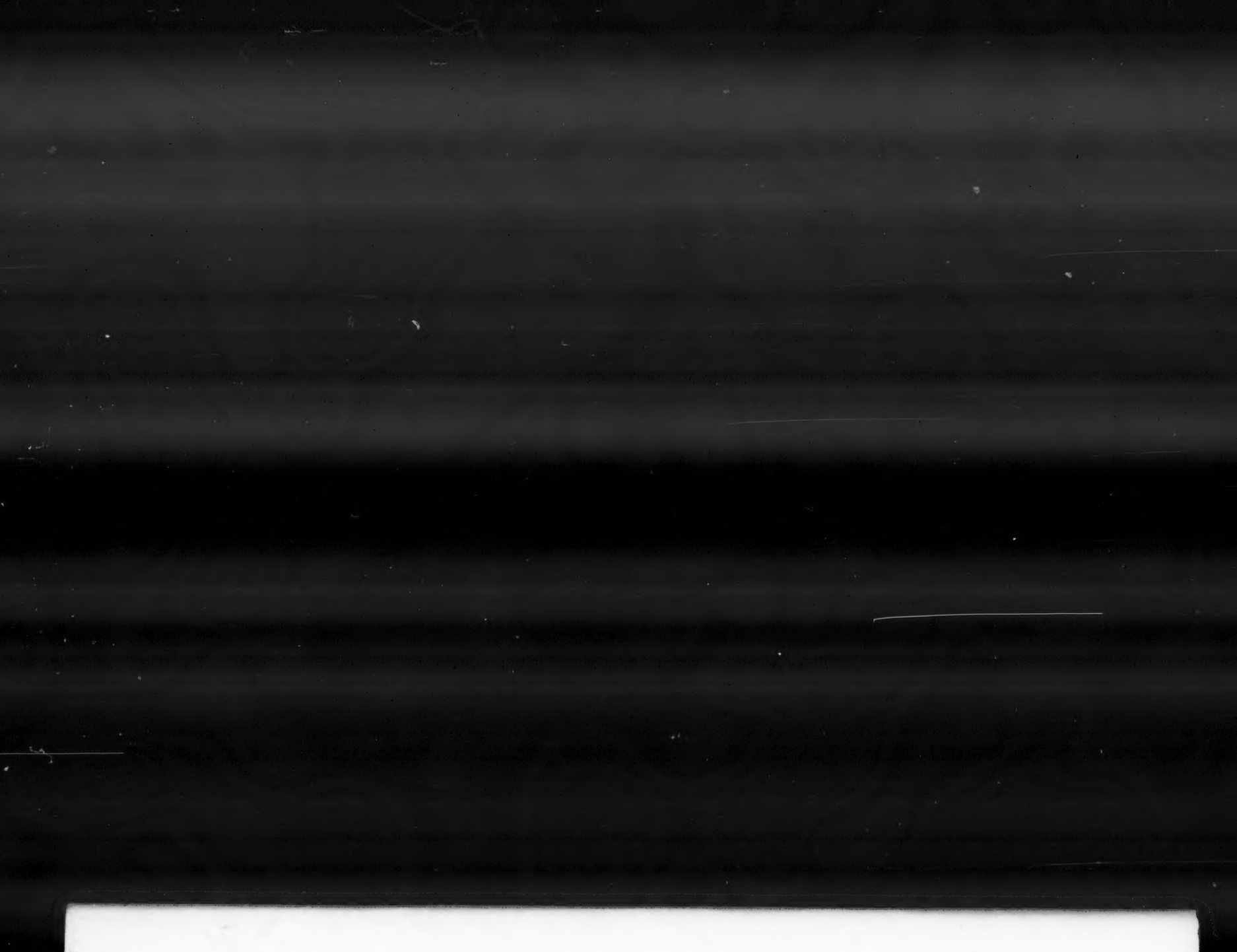
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